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THE NEWER APPALACHIANS OF THE SOUTH

PART I. BETWEEN THE POTOMAC AND NEW RIVERS

FRANK J. WRIGHT

Received November 20, 1933; published April 30, 1934

CONTENTS

Advance Summary

The paper deals with the erosional and drainage history, and the special features of the Newer Appalachians from the Potomac southward to the New River. The erosional history is studied under four heads, pre-Schooley history, the Schooley cycle, the Harrisburg cycle, and the post-Harrisburg cycle.

Special emphasis is laid upon the great importance of Harrisburg erosion in the development of the present topographic features of the region. During this cycle, the Harrisburg peneplane, and numerous local peneplanes and mature valleys in the Appalachian Ridges were produced. These features are tentatively correlated with the Piedmont peneplane to the east. An upstream ascent characterizes these surfaces, and it is steepest in those basins where the peneplane was only locally developed. Because of this upstream rise, the present elevations of different basins produced in the same cycle vary hundreds of feet. The higher basins grade down to the lower ones and the entire series constitutes a large group of related and coördinated features. This principle, correctly applied, is the key to the explanation of erosion levels in many parts of the area.

During post-Harrisburg time, the Valley peneplane has been only slightly dissected in some places, maturely dissected in others, and in still other regions it has been reduced evenly in amounts that vary from locality to locality. These conditions, especially the last named, have caused some observers to recognize a series of peneplanes below the Harrisburg. The writer finds slight evidence of one interstream level lower than the Harrisburg, in addition to a rather extensive development of stream terraces. There are almost level areas which apparently have been reduced rapidly and uniformly since the uplift at the end of the Harrisburg cycle.

Drainage problems are considered from the standpoint of regional and local types. The southeast-flowing superposed streams of the region are described. A problem involving the upper Roanoke River basin is treated at some length and an explanation of the piracy of the Roanoke is attempted. The area

now drained by North and South Forks of Roanoke River formerly discharged to New River, before it was transferred by capture to the Roanoke.

After a consideration of minor drainage changes, and structural types of ridges and valleys, some of the outstanding special features of the region are treated in the concluding section. Such characteristic limestone features as natural chimneys, limestone sinks, and lost rivers are briefly described.

The paper ends with a detailed consideration of the history of the Natural Bridge region. From field and laboratory studies of the area between Lexington and Buchanan, the writer is convinced of the existence of a southeast-facing escarpment which reaches its maximum height of 250 feet between Natural Bridge and Natural Bridge Station. Cedar Creek, the stream that flows under the Bridge, crosses the escarpment. This feature is apparently due to the difference in elevation between the higher Harrisburg surface produced by subsequent tributary streams on the one hand, and the lower Harrisburg surface of James River on the other. If this be true, Cedar Creek could not have occupied its present position in the Harrisburg cycle. It may have been diverted from its ancestral course across Sallings Mountain to its present position under Natural Bridge through the development of a sink drainage basin west of the escarpment whose subterranean outlet emptied into a tributary of James River to the east.

Introduction

An essay entitled "The Older Appalachians of the South" (*71*) was published in 1931. This was an effort on the part of the present writer to trace the erosional history of that part of the southern crystalline area which is called by Fenneman and others, the Blue Ridge Province. One of the main points in that paper was the correlation of numerous high-lying local peneplanes with each other and with the Valley peneplane on the west and the


MEADOW BLUFF
HINTON
WILLIAMSBURG
MUDDY CR.
ANDERSON
LEWISBURG
GREENBRIER R.
SINKS GROVE
PICKAWAY
ANTHONYS CR.
W. VA.
VA
PETERSTOWN
INDIAN CR.
UNION
STONY CR.
DUNLAP CR.
SWEET CHALYBEATE
PEARISBURG
W. VA.
VA.
POTTS CR.
COVINGTON
PAINT BANK
SINKING CR.
JOHNS CR.
NEWPORT
SINKING CREEK
NEWCASTLE
BLACKSBURG
NORTH FK
CATAWBA CR.
EAGLE ROCK
FAYETTE
MASON
CHRISTIANSBURG
ROANOKE R.
FINCASTLE
CEDAR
ELLIOTT CR.
SOUTH FK
DALEVILLE
BUCHANAN
JAMES R.
CAVE
BACK
SPRING
CR.
ROANOKE
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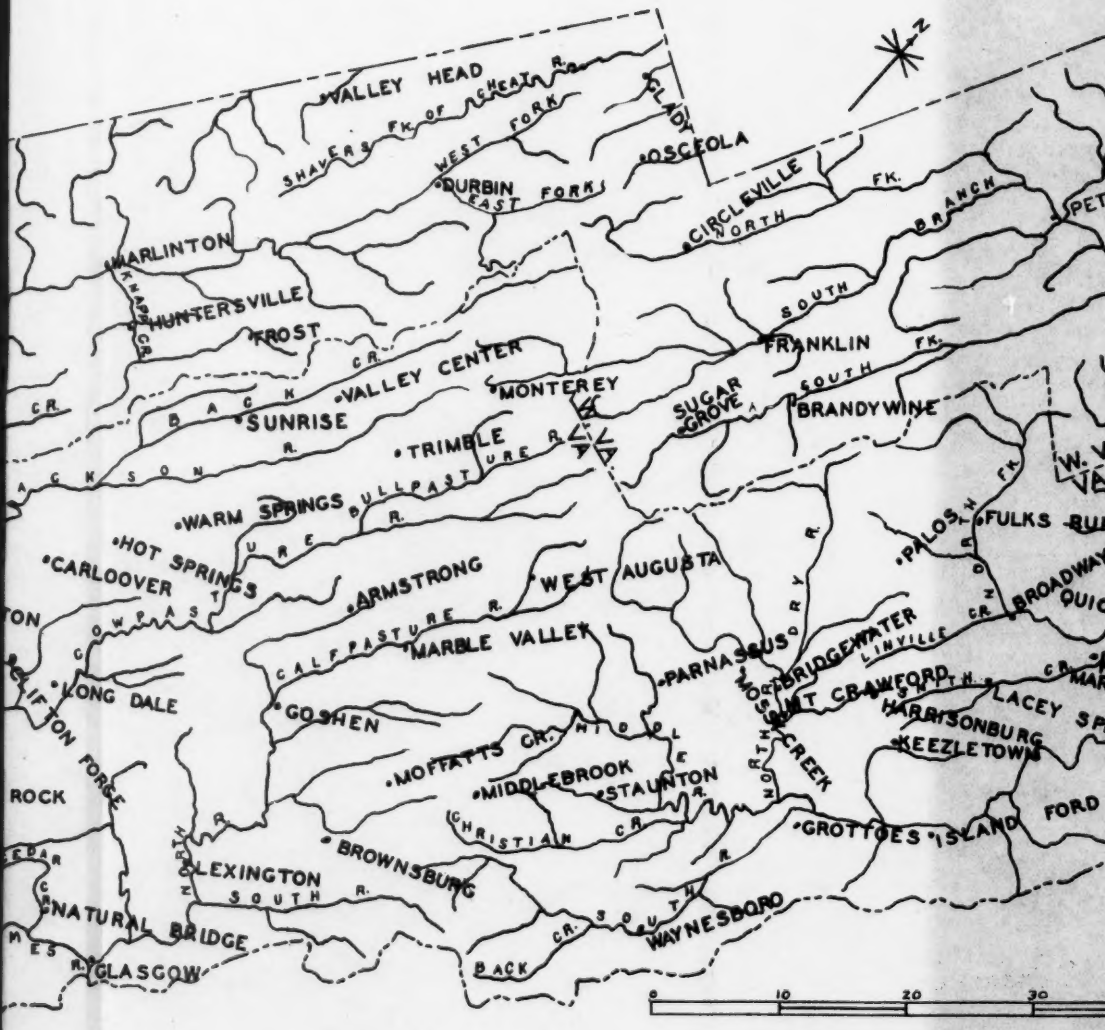

FIG. 1. MAP SHOWING THE MAIN DRAINAGE LINES BETWEEN POTOMAC AND NEW RIVERS
(From state maps published by the United States Geological Survey and the West Virginia Geological Survey.)

ERS
eal Survey.)

Piedmont peneplane on the east. The tentative correlation of the Piedmont with the mountain peneplanes is still a question, but the other correlations seem to be reasonably well established. The extension of the Harrisburg erosional record from the regional peneplane of the Valley into the high mountains has tended to simplify and unify the later erosional history of this region.

In 1932, the author set out to extend the study from the Older Appalachians into the Newer Appalachians.[1] Field work was undertaken in the summer of 1932, and continued in 1933. For the purpose of this study the region is divided into two parts: the first extends from the Potomac south to the New River (Fig. 1); the second comprises that part of the drainage area of the Tennessee River above Chattanooga which lies within the province. These two parts of the Newer Appalachians south of the Potomac are contrasted in their structural types of ridges,

[1] The terms Older and Newer Appalachians are used in this paper in their usual sense to denote two large, sharply contrasted Appalachian provinces, the rocks of which for the most part differ from each other in age. The terms are not satisfactory to the Publication Committee of the Geological Society of America and not entirely satisfactory to the present writer. The Publication Committee objects to the use of these terms as province names on the ground that Newer and Older have no reference to their relative ages but to the ages of the rocks involved. "Appalachian Valley and Ridges" is employed by members of the U. S. Geological Survey and others for the province which is here called the Newer Appalachians.

To make clear to the reader the usage of province names as employed in this paper, the following definitions are given:

"Appalachian Highlands" includes the entire Appalachian region from the Coastal Plain on the east to the Interior Lowland on the west. "The Appalachians" will not ordinarily be used, but may be employed as an abbreviation for "Appalachian Highlands," where the meaning is clear. In like manner, "Northern Appalachians" and "Southern Appalachians" are convenient abbreviations for Northern Appalachian Highlands and Southern Appalachian Highlands. The writer uses the Potomac River as the dividing line between the Northern and Southern Appalachians.

The Newer Appalachians are divided into two parts, each with province rank. The eastern division is called the "Appalachian Valley," and the western the "Appalachian Ridges." "Valley" is occasionally used for "Appalachian Valley" to avoid needless repetition where the meaning is obvious; in like manner, the term "Ridges" refers to "Appalachian Ridges."

"Appalachian Plateau" is used in its usual sense to include the area of essentially horizontal sedimentary rocks west of the folded mountains. Its eastern margin is in many places a bold escarpment known as the "Allegheny Front."

and in the extent of development of subsequent drainage. The northern part will be considered in the present paper, while the southern half will be treated in a later essay.

ACKNOWLEDGMENTS

The writer gratefully acknowledges the receipt of a grant from the Penrose Fund of the Geological Society of America. This assistance has enabled him to undertake the study of a larger area than was previously anticipated and has made it possible for him to present as a unit the results of studies covering a period of years. The money was used for field expenses, clerical assistance, and plates. Thanks are due Mr. Marius R. Campbell for accompanying the author on an eight-day field trip during the summer of 1933 and for valuable criticisms on the manuscript. It is a pleasure to acknowledge the encouragement that has come from President Avery A. Shaw of Denison University.

REVIEW OF THE REGIONAL HISTORY

The erosional history of the Southern Appalachians is a long story. It has continued, with interruptions of more or less importance, since the Appalachian Revolution. The region has experienced peneplanations, uplifts, and possibly burial beneath the sea. In a general way, however, this long history may be divided into four parts, the earliest consisting of a cycle or cycles, the traces of which are extremely difficult to detect. The second part was a long cycle which culminated in the formation of the Schooley peneplane. This was followed by a much shorter cycle during which the Harrisburg peneplane was developed. The last part of the history comprises the relatively short period of time during which the Harrisburg peneplane has been dissected to a greater or less extent, and various terraces produced. This outline of the erosional history of the region is designed to be flexible enough to permit the introduction of additional cycles as their existence is demonstrated. Only the events that are prominently represented in the present topography are here included.

Concerning the first part of the story, little is known. The

traces of peneplanes assigned to this period have not been satisfactorily correlated. Even with the coming of fuller knowledge of these earlier cycles, the restoration of the erosional surfaces produced during them will be the problem for the painstaking expert who is prepared to make accurate and meticulous discriminations. For regional and practical purposes, such remnants may be considered as monadnocks on the Schooley peneplane. There is, however, one large problem in this early and obscure record that must receive attention in the Southern Appalachians as it has already received in the Northern. This is the question of the superposition of master streams across the ridges. The James and Roanoke flow to the southeast through the mountains while the New flows to the northwest.

The second part of this history involved a long cycle. The Schooley peneplane, the product of this cycle, can be traced with reasonable certainty in many parts of the Southern as well as in the Northern Appalachians. In general, its surface is preserved only on the more resistant rocks where, during Harrisburg and later time, there was only moderate dissection. Some of the more important problems in this period of Appalachian history are the more accurate determination of the present position of the Schooley peneplane, the nature and amount of deformation which it has experienced, and its relation to the Harrisburg peneplane.

The third chapter of the history is represented by the Harrisburg or Valley cycle during which a fairly perfect peneplane was developed on soft rock areas and, under special conditions, also in regions of moderately resistant rocks. Because of its splendid preservation in many places, it offers to the student of peneplanes many interesting problems for investigation, among which is the correlation of erosion surfaces produced at different elevations in the same cycle. Other lines of profitable inquiry include a more careful consideration of those areas which seem to be lower than the Schooley and higher than the Harrisburg, and a more accurate analysis of the nature of typical Harrisburg topography.

The latest part of the erosional record, unlike the earliest, furnishes us with many facts, but the interpretations of them by

different workers are quite diversified. Some of the grounds for this diversity are involved in the idea of the peneplane itself. Other problems involve the importance of solution in lowering interstream areas, and the effects of differences in rock resistance. Finally, the terraces, especially prominent in the valleys of James and New Rivers, have not yet received adequate treatment.

In the later part of the erosional history, there were drainage changes of considerable importance in many parts of the area. These, along with the problems enumerated above, are some of the open questions in the Southern Appalachians. The writer does not hope to solve at this time any large number of them, but he does wish to offer some suggestions based on field and profile studies which may be helpful in unraveling the history.

BOUNDARIES

The Newer Appalachians south of the Potomac comprise a long belt, fifty to seventy miles in width, extending as far south as central Alabama. The reader who wishes to trace the boundaries is referred to Fenneman's map (*29*). An excellent description of the Valley of Virginia is contained in a bulletin by Stose and others (*56*). For the most part, the southeastern margin is sharply marked by the steep western slope of the Older Appalachians, (Blue Ridge Province). The bold western front of the Older Appalachians is a conspicuous feature as viewed from the west, except in the extreme south where the Appalachian Valley comes in contact with the Piedmont. As one passes from west to east in northern Alabama and Georgia, he rises from the floor of the Valley to the somewhat higher level of the Piedmont. The western boundary of the province is likewise sharp in most places, particularly in northern Virginia and West Virginia where the Allegheny Front is especially prominent. This feature is well developed where crossed by U. S. Highway No. 50, west of Romney, West Virginia, and in the northwestern corner of the Monterey, Virginia-West Virginia quadrangle, where it bears the local name of Cheat Mountain. An unusual expression of the scarp is seen along U. S. Highway No. 60 west of Lewisburg,

West Virginia, where a bold intermediate bench breaks the scarp into two parts.

The Newer Appalachians Province considered as a whole comprises two contrasted divisions. The eastern part is the Appalachian Valley which is not broken by any transverse ridge from Birmingham to Montreal, but is split lengthwise in several places by ridges such as Massanutten Mountain in Virginia. The width of this Valley varies from less than two miles at Buchanan, Virginia to almost fifty miles in its extreme southern portion. It is a lowland on limestone and shale, drained in the northern section by southeast-flowing streams with subsequent tributaries, and in the south by master subsequent streams.

The western part of the province is here called the Appalachian Ridges. It is characterized by sandstone ridges, trending northeast and southwest, separated by limestone and shale valleys. In some places, as in the Staunton-Monterey area, there are as many as eight or ten parallel ridges.

The essential nature of folded mountain topography is the same in the Appalachians as in other areas of folded rocks. The folds have been truncated by erosion, and consequently the rock formations are exposed in parallel belts. The harder ones stand out as ridges and the weak ones underlie valleys. Linear ridges separated by valleys, which are mostly subsequent, are the most characteristic topographic features of this region. The typical trellis drainage pattern is found in many parts of the province.

The Appalachian Ridges do not extend quite as far south as the Appalachian Valley. They are more numerous in Virginia and West Virginia and become fewer toward the south. Except in the far south, an east-west profile across the province always brings out on the west a number of parallel ridges, ranging from one or two up to ten, and on the east, a broad valley or lowland. In its most typical parts, this group of features is bounded by the wall of the Allegheny Front on the west and the steep western slope of the Older Appalachians on the east.

Pre-schooley Erosional History

There is at present no way of definitely dating the beginning of the Schooley cycle of erosion in the Appalachians. Judging from the comments of some writers, it may have started as late as the Tertiary period, while others would place it wholly within the Cretaceous. Between the time of the folding of the Appalachians and the beginning of the Schooley cycle there was a very long span of geological time, embracing the Triassic and Jurassic periods and possibly part or all of the Cretaceous. The record of the events which transpired within this time is but meagerly known. In view of the total absence of sediments of that age, erosional processes were certainly dominant in the area under consideration. It is likely that one or more peneplanes were produced, and the work of Johnson, Stose, and others, in the Northern Appalachians seems to confirm this possibility. In the present discussion, this entire period is referred to as pre-Schooley.

Stose recognizes three peneplanes older than the Tertiary in the western part of Virginia, and he applies to them the terms Summit, Upland, and Intermediate, the Summit being the oldest. He finds traces of them in the Blue Ridge as well as in the linear ridges to the west. Thus he says (*56*), "The highest peneplain that is recognized in Virginia ranges in altitude from 3,500 to 4,000 feet above sea level. Near the Potomac the Blue Ridge seems to have been entirely eroded below this level by later erosion. Near Luray broad flats and gentle divides on the tops of the Blue Ridge at 3,500 feet altitude probably represent the peneplain, above which stand Stony Man and other peaks that were unreduced and are about 4,000 feet in altitude. . . . . The higher ridges in the valley have similar elevations. The massive Shenandoah or Great North Mountain is the chief mountain mass within the valley in the northern part of the State that persists at the highest level. Its rounded summits are mostly between 3,500 and 4,000 feet, but one peak and an outlying knob near Staunton are distinctly above the level and rise to nearly 4,500 feet altitude. Between Shenandoah Mountain and Allegheny

Front in West Virginia are many straight narrow ridges whose tops also vary between 3,500 and 4,000 feet." Stose correlates the Upland peneplane with the Kittatinny peneplane of the Northern Appalachians. According to him the next lower surface, the Intermediate peneplane, corresponding to the Weverton peneplane in Maryland, "is indicated by the even tops of foothill ridges, spurs, and knobs of the Blue Ridge and by some low divides in these mountains about 2,200 to 2,300 feet in altitude."

In a paper entitled, "The Geology of Little North Mountain in Northern Virginia and West Virginia," Giles (*32*), following the terminology of Stose, described remnants of the Summit peneplane. In this connection, he says, "The crests of Great North Mountain and its neighbors in northern Virginia rise to levels above 3,500 feet. Their accordant summits are interpreted as remnants of a once continuous plain which extended over the whole region and which has been named the Summit Peneplain." He also finds the lower peneplanes described by Stose.

Another worker who has found traces of a peneplane older than the Schooley is Woodward (*69*). In his report on the "Geology and Mineral Resources of the Roanoke Area, Virginia," he describes four peneplanes including the Summit, Upland, Intermediate, and Valley Floor. The Summit peneplane is represented by Poor Mountain in the Older Appalachians, southwest of Roanoke. Its highest point reaches an altitude of 3960 feet. Woodward also cites Mason Knob, McAfee Knob, and Fort Lewis Mountain, which range from 3201 to 3328 feet in elevation, as features which rise almost to the level of the Summit peneplane. He apparently means to suggest that they may be the eroded remnants of this peneplane.

Some of the most suggestive remnants of a pre-Schooley peneplane are found on either side of the New River where it breaks through the Appalachian Ridges on its way to the Ohio River. These features appear on the Dublin, Virginia-West Virginia, quadrangle, and they have been described by Hubbard and Croneis (*37*) in a paper published in 1924. These authors correlate the levels of Giles County, Virginia, with those previously described by Stose. The highest peneplane, corresponding to the

Summit Peneplane of Stose, is described in the following manner: "Doe Mountain, Pearis Mountain, Angels Rest, and portions of the crest line of Peters and East River mountains have a fairly uniform height of 3500 feet. This elevation represents a former peneplain surface, which probably was completed in late Jurassic time. In this paper, this peneplain will be referred to as the Pearis Peneplain. Above this early plain, which was then close to sea level there rose monadnocks to the height of 200 to 800 feet. Today Bald Knob, Butt Mountain, and portions of Sugar Run Mountain remain as remnants of these former elevations."

At various times the present writer has made projected profiles across the region extending from the Appalachian Plateau on the west to the Piedmont on the east. These profiles have not revealed any marked accordance among the elevations which rise appreciably above the Schooley level. He has likewise examined these eminences more or less carefully in the field. In addition to the specific localities mentioned by the preceding writers, there are other scattered peaks in the Appalachian Ridges and especially in the Blue Ridge which rise to or above the level of the Summit peneplane as suggested by Stose.

In view of the fact that such an extremely long period of erosion would indicate at least one peneplanation, it seems quite logical to assign to the peneplane the position represented by some of these higher features. Nevertheless they are so few in number, so variable in elevation, and so widely scattered, that any attempt to locate definitely the present position of the peneplane is hazardous. The mountains which are supposed to preserve this level are seldom characterized by flat surfaces. They are, in fact, quite like monadnocks.

We have come to look upon the Schooley cycle as a very long period of erosion during which the Appalachian Highlands were brought down to a fairly even surface. Until we know the amount and nature of the uplift which closed the earlier cycle and inaugurated the Schooley, it will not be possible to estimate the expectable difference in elevation between the remnants of the earlier peneplane and the preserved parts of the Schooley surface. This fact adds to the difficulty of the problem of restoration.

In view of the fragmentary nature of the isolated remnants of the so-called Summit peneplane, it seems wise to leave it out of consideration as an identifiable feature in the Newer Appalachians of the South. This is not to be understood as a denial of the existence of such a peneplane, but rather a hesitancy to designate a feature which is supported by such slender field and map evidence.

The Schooley (Upland) Cycle

GENERAL STATEMENT

The writer has not found dependable evidence of two closely associated peneplanes, corresponding to the Schooley and Kittatinny, as they have been described in the Northern Appalachians. The term Schooley, which is apparently more widely used than Kittatinny, is employed for the single, upland erosion level described in this report. The term, Upland Peneplane, used by Stose (*56*) and Wright (*70*) is regarded as an acceptable synonym, and in some respects it is to be preferred to Schooley, especially in the Southern Appalachians. This peneplane has been described for different parts of the region by Stose and Miser (*56*), Giles (*32*), Woodward (*69*), Hubbard and Croneis (*37*), and Wright (*70*). These references all apply specifically to the region under consideration. The list can be considerably augmented by referring to the bibliography at the end of this paper. Reger (*49*), in his report on Mineral and Grant Counties, West Virginia, calls attention to New Creek Mountain, "with elevations from 2550 to 3100 feet," Patterson Creek Mountain, and Huckleberry Ridge as possible remnants of this peneplane. Reger does not recognize any peneplane older than the Schooley.

In view of the widespread development of this erosion level, it is very obvious that the cycle during which it was produced was exceedingly long. Even if the features which have been inter-

preted by some writers as remnants of an earlier peneplane be included as monadnocks above the Schooley level, the total number of erosion remnants left above this surface is surprisingly small. This is particularly true in the Newer Appalachians. The number of erosion residuals is much greater in the Older Appalachians of North Carolina and Tennessee. The area of folded rocks was almost perfectly peneplaned in this cycle, but this does not mean a perfect flatness.

In folded rocks, especially where the dips are steep, the belts of resistant rock are relatively narrow. The width of outcrop varies from fold to fold and also along the strike of the same fold, because of variations in the dip and thickness of the formation. Variations along the strike are also caused by changes in the lithology. Too much emphasis has undoubtedly been placed on elevation, and evenness of skyline, as criteria for the recognition and identification of peneplanes in the Appalachians. Some of the most even skylines have no relation to peneplane levels. A good illustration of this fact is the remarkably even crest of Walkers Mountain (*70*) west of Staunton, Virginia, which is merely an unbreached anticline. Accordancy in elevation of a series of parallel ridges is a much better basis of correlation, but even this is not wholly trustworthy because the ridges may have been reduced uniformly and at a more or less rapid rate than their neighbors of more diversified elevations. We must also recognize the fact that even the well-developed Schooley peneplane must have had low features on its surface which were scarcely distinctive enough to be called monadnocks. Furthermore, as shown by Ver Steeg (*60*), the surface sloped toward the main drainage lines.

Taking the above facts into consideration, the writer is quite convinced that it is impossible to restore with a high degree of accuracy the Schooley level in the folded mountains. All of the ridges have been reduced somewhat since the uplift of the Schooley peneplane and some more than others. The best that can be done is to approximate the present elevation through the use of closely spaced profiles across the region. This reduces the human error. If the profiles are then checked in the field, one

can estimate the present level of the Schooley peneplane with a probable error of several hundred feet. If it happens that an even-crested ridge has the same elevation as the restored peneplane in that locality, one points to that ridge as a remnant of the Schooley peneplane. It is indeed quite possible that in some localities no one ridge closely approximates the present level of the peneplane.

MONADNOCKS ON THE SCHOOLEY PENEPLANE

It is difficult to find a typical monadnock in this region rising sharply above the general level. In the first place the level is not very well marked, and in the second, the eminences on the ridge crests usually rise so gradually above the general level of the crest line that they do not form conspicuous features.

Elliott Knob, a rather prominent peak in the western part of the Staunton qudarangle, has an elevation of 4473 feet, and is the highest mountain in that part of Virginia. The peneplane thereabouts has an approximate elevation of 3500 feet. Northeast Peak in the southeastern corner of the Monterey quadrangle is a less impressive monadnock, as is also Sounding Knob near Monterey. The last two rise only a few hundred feet above the peneplane level.

The high mountains through which New River flows in the vicinity of Pearisburg, Virginia, may be monadnocks. These include Angels Rest, Sugar Run, Butt, and Salt Pond Mountains. Bald Knob, 4348 feet in elevation, rising sharply above Salt Pond Mountain, is certainly a monadnock.

REMNANTS OF THE SCHOOLEY PENEPLANE

From the forest lookout tower on Massanutten Mountain east of Woodstock one has a commanding view, not only of the valley of the North Fork of Shenandoah River with its magnificent meanders, but also a very striking view of North Mountain which forms the western skyline. Farther north it is called Great North Mountain. It is rather impressively even, and since its average elevation of 3000 feet is about the same as the restored Schooley

peneplane in that part of Virginia, it is possible that this mountain preserves the Schooley level.

Massanutten Mountain, which splits the Valley of Virginia between Strasburg and Harrisonburg into two parts, maintains fairly well the Schooley or Upland level, though in many places it has been eroded below the peneplane.

The elevation of the peneplane increases toward the James River basin. Allegheny Mountain, ten miles west of Monterey, Virginia, preserves the Upland peneplane perhaps as accurately as any ridge in western Virginia (*Plate I*). The structure of this mountain is that of a broad syncline. As a consequence, the exposed belt of resistant rock is relatively wide. The elevation of the peneplane on this mountain, north and south of the Staunton-Parkersburg Pike, is approximately 4350 feet. From this point the peneplane descends appreciably toward the southeast. In an earlier paper the writer (*70*) has described this and other remnants of the Schooley or Upland peneplane, and the reader is referred to this report for a fuller discussion of these remnants.

Passing on toward the southwest, the Schooley descends to elevations between 3000 and 3500 feet in the northern part of the Christiansburg quadrangle. A number of the mountain crests average between 3000 and 3250 feet. Approaching New River, some of the mountains become distinctly higher. There does not seem to be, however, much accordancy among them and the writer is inclined to regard them as monadnock features. Angels Rest at the north end of the synclinal Pearis Mountain enjoys a structural advantage which probably accounts for its broader outcrop of resistant rock and consequently its higher elevation. At the same time, there are other mountains whose crests exceed 3500 feet. They may represent the remnants of an earlier peneplane, or unreduced erosion remnants above the Schooley peneplane. On the basis of regional studies, the writer is inclined to place the Schooley peneplane between 3000 and 3300 feet in the area of folded mountains adjoining New River.

WARPING OF THE SCHOOLEY PENEPLANE

In the preceding paragraphs it has been pointed out that the Schooley peneplane rises from an elevation of about 3000 feet in northern Virginia to somewhat more than 4000 feet near the head of the James River, and then declines to between 3000 and 3300 feet in the New River basin. In the paper referred to above, the present writer considered at some length the evidence of warping in the upper James River basin. At present there seems to be no reason to modify the earlier statements as to regional warping, but he is inclined to question the sufficiency of the evidence in support of the small domal warpings in the Appalachian Plateau.

It seems to be reasonably well established that the zone of maximum uplift of the Schooley peneplane was located along the Allegheny Front in the eastern part of West Virginia, with its greatest elevation in the area around Durbin. If we could know with certainty the direction of flow of the streams in the Schooley cycle, we would have some idea as to what part of this slope is original. The peneplane unquestionably slopes to the southeast, as well as to the northeast and southwest, from this central higher area around Durbin. This slope is doubtless due in part to the normal downstream slope of erosion surfaces. A map showing a restoration of this peneplane accompanied the report referred to above. While the restoration of the peneplane in the Appalachian Plateau is in general easier than in the Appalachian Ridges, it is possible that, in the extreme western part of the area covered by the map, the Harrisburg peneplane, rather than the Schooley, is preserved by the accordant mountain tops. If this is the case, the map exaggerates the steepness of the northwest slope of the restored Upland peneplane where the two peneplanes come together.

The Harrisburg (Valley) Cycle[2]

GENERAL STATEMENT

The relief features of the Newer Appalachians of the South are due in large measure to Harrisburg and post-Harrisburg erosion. As already explained, the monadnocks which rise higher than the Schooley level are relatively few. The Schooley surface itself does not make up a large part of the terrain, and the elevations of its remnants are so variable that one could classify the topographic elements in many parts of the province as Harrisburg monadnocks, Harrisburg surface, and post-Harrisburg valleys.

With the uplift which brought the Schooley cycle to a close, the rejuvenated streams began a vigorous attack. It is perfectly obvious that the Schooley surface was by no means a perfect peneplane, and it is equally obvious that the variations in the resistance of the rocks exposed on its surface was enormous. Different phases of the same rock formation may show marked contrasts in erosive resistance. Furthermore, there appears to be a considerable difference in the rate of lowering of interstream areas in limestone as compared with shale and other less soluble rocks.

EXTENT AND NATURE OF HARRISBURG EROSION

The Harrisburg is essentially a weak rock peneplane, although there are exceptions. Wherever weak rocks were exposed at the close of the Schooley cycle or shortly after the beginning of the Harrisburg cycle, the Harrisburg peneplane was usually developed. Since there is every grade of rock resistance from the weakest to the strongest, the line between weak and resistant rocks is quite an arbitrary one. The weaker the rocks the

[2] It must be borne in mind that there may have been a cycle or cycles of erosion between the Schooley and the Harrisburg. Stose (*56*) has found and described what he terms the "Intermediate peneplain" in Virginia which would represent the work of such a cycle. The present writer has been unable to find sufficient evidence of an erosion level between the Schooley and the Harrisburg to justify its inclusion in this outline of the erosional history of the Newer Appalachians, the purpose of which is to include only those erosion features that can be identified with comparative ease and certainty in the present state of our knowledge.

greater the likelihood of the area being peneplaned. Other factors which must be taken into account include proximity to the main drainage lines, the presence or absence of resistant rock across the stream courses, and, to an extent, the arrangement of drainage lines with reference to the weak rock belt. It is quite apparent that where the strips of weak rock were narrow, as in some of the valleys in the Appalachian Ridges, there could be only a mature valley in Harrisburg time. Where the belts were broader, local peneplanes were produced.

As a general proposition, the Harrisburg surface was best developed in the broad expanse of limestone and shale in the Appalachian Valley. A regional peneplane, in many places almost perfectly even, was developed there. In other places where beds of cherty limestone alternate with purer limestone, the surface was doubtless corrugated at the end of the cycle. From the Appalachian Valley, where the peneplane is broadly developed, the surface may be traced up many of the tributary valleys between the ridges on the west, and also into the crystallines to the east. At the southern end of the Older Appalachians the reduced Harrisburg surface of the Appalachian Valley is probably correlatable with the slightly higher Piedmont peneplane on the crystallines to the east. At Roanoke, Virginia, the level is traceable along the Roanoke River from the Valley into the Piedmont. Above and below the water gaps of the James and the Potomac at Balcony Falls and Harpers Ferry respectively, the Valley level articulates with the Piedmont level to the east.

Another important characteristic of the Harrisburg surface is its definite and sometimes steep upstream ascent. Failure to recognize this fact would lead to many errors in estimating the present elevation of the peneplane and also in attempting correlations. It rises not only upstream, but also toward the sides of the valley. Except locally, the Harrisburg is not a level surface but always slopes down in the direction of the flow of the drainage lines. This is true for both the master stream and its tributaries. In view of the fact that this downstream slope is practically universal in the Southern Appalachians, regardless of the direction of flow, we must conclude that it is essentially original and not due primarily to warping.

By reason of the upstream rise of the peneplane surface, it is obvious that the present elevation of its surface will vary from place to place in the same lowland as well as between nearby areas that are drained by different streams. Hence correlations based solely on elevation would have little value. On the other hand, elevation is an important criterion in a study of these surfaces if carefully applied. In giving a value to the present altitude of the Harrisburg surface, it is necessary to bear in mind several facts. The upstream rise has already been mentioned. Elevations taken too close to the present valley may represent the valley bottom in Harrisburg time and consequently would be too low for the peneplane. Furthermore, vigorous erosion adjacent to the main stream tends to lower this part more than the average. Values taken back near the base of a bordering ridge are usually a little higher than the mean peneplane level for the lowland at that point. Elevations taken between these extremes are more reliable. Another point, which will be elaborated more fully in a later section, has to do with the relatively rapid lowering of the interstream areas in limestone districts. The writer is of the opinion, after a study of many localities in limestone regions of the Southern Appalachians, that the large percentage of the precipitation which sinks immediately underground will lower the surface of a peneplane almost uniformly in a belt of highly soluble limestone. Such surfaces may be several hundred feet, in extreme cases, below the elevation which the Harrisburg peneplane had at the time of its uplift. When limestone and shale occur in parallel belts, the shale area may stand 150 to 200 feet above the limestone, and both areas seem to be perfectly well peneplaned. Some have interpreted these conditions as representing distinct peneplanes formed in different cycles. The writer would be inclined to regard the shale area as representing the slightly lowered Harrisburg level, and the limestone belt as an area that has been reduced more rapidly than the shale, and uniformly so as to maintain an even surface.

The viewpoint of Stose, which is somewhat different from the one here expressed, should be set forth. In referring to the dissection of "valley-floor peneplains," he says (*56*), "Later

erosion of the softer rocks to a new low level, 100 to 500 feet lower than the valley-floor peneplains, is believed to have occurred in late Tertiary time, probably just before and during Pliocene time. This lower valley floor is considered to be of the same age as the peneplain so well marked along the Atlantic coast by high-level gravels, formerly called Lafayette. In the Appalachian Valley this epoch of erosion is chiefly represented by low flat divides in the valley floor of longitudinal valleys underlain by soluble or soft rocks, and by terraces and benches on somewhat harder rocks along the transverse trunk streams. These terraces are well marked along Potomac River but cannot be definitely traced far from the river except up the main tributaries. The valley floor of Salem Valley, 1,000 feet in elevation, was probably formed at this time, when Roanoke River robbed the James of one of its large branches that formerly drained this valley."

MONADNOCKS ON THE HARRISBURG PENEPLANE

The erosion remnants, which at present rise as high as the Schooley peneplane, presumably belong to the Schooley record. Their elevations above the present Harrisburg surface vary from several hundred to several thousand feet. It is obviously quite arbitrary to attempt a meticulous separation of Harrisburg monadnocks from the remnants of the Schooley peneplane, but a fair separation can be made in most localities. Ridges which are just slightly below the average level of the Schooley peneplane are interpreted as Schooley remnants which have suffered much from post-Schooley erosion.

In this section, we are concerned only with those remnants which in elevation are more or less closely associated with the Harrisburg level. There are in general two types, the conical or oval-shaped, and the elongated or ridge-like. One may cite as examples of the former, Mole Hill near Dayton, Virginia (*Plate II*), Round Hill at Bridgewater, Virginia, and Mary Gray and Betsy Bell overlooking Staunton, Virginia. The ridge type of monadnock is illustrated by lines of chert hills such as those west of Harrisonburg, Virginia, and even better by Bays Mountain, Tennessee.

The monadnocks are composed for the most part of cherty limestone, and their size and distribution depend largely upon the shape and extent of these hard rock belts. The greater the distance from the main drainage lines, the less perfect the peneplanation in the Harrisburg cycle and consequently the greater the number of monadnocks. In limestone regions, however, there is not the contrast in number of monadnocks between upstream and downstream situations which is frequently found in crystalline areas. The limestone is more uniformly weak than the crystallines and is distinctly weaker, in most cases, than the rocks with which it comes in contact with the exception of shale. Consequently, there are fewer monadnocks on the Harrisburg surface where it was developed on limestone than in areas underlain by crystalline rocks. This statement cannot be taken too literally because there is a considerable variation in resistance among different limestones.

In some parts of the province, the linear monadnocks are so nearly accordant that some workers have interpreted them as remnants of a peneplane. This is illustrated in the Shenandoah Valley of Virginia by the work of Watson and Cline (*66*). The interpretation of these features as peneplane remnants is open to question. In the first place, there is practically no flat surface preserved on their crests. Sharp ridge crests are not very reliable evidence on which to base the restoration of a peneplane. In the Shenandoah Valley region, they are almost entirely on the cherty members of the limestone. In view of the relatively brief duration of the Harrisburg cycle as shown by the degree of slope of its erosion surface, it is reasonable to assume that the cherty limestone belts were somewhat embossed upon that surface at the close of the cycle. Furthermore, since the beginning of post-Harrisburg time the purer limestones have certainly been lowered more rapidly than the silicious. Finally, these monadnocks are not numerous or accordant enough to have great significance in indicating the position of a level. For these reasons, the addition of such a cycle in the erosional history of the region would seem unnecessary.

SUMMARY OF HARRISBURG EROSION

Although the Harrisburg was a cycle of relatively brief duration, the streams of that time were able to reduce the less resistant rocks to lowlands of slight relief. The broad belt of weak rocks in the Appalachian Valley was brought down to a regional peneplane at elevations varying from approximately 550 feet near Harpers Ferry to a maximum of nearly 2600 feet on the divide between the New and Holston Rivers. In addition, there were arm-like extensions of this regional peneplane into the crystallines to the southeast and the ridges to the northwest. Some of these are broad enough to be called local peneplanes while others are merely the remnants of mature valleys of the Harrisburg cycle.

In areas of more resistant rock, the stage of development attained in the Valley cycle varies from moderate dissection, as shown in Plate I, to areas that were maturely dissected. Along the Allegheny Front west of Marlinton, Lewisburg, and Hinton, West Virginia, there is an intermediate level between the Schooley and the Harrisburg surfaces which the writer interprets as due primarily to structure. This bench, with its associated features, is apparently a product of Harrisburg erosion.

The Appalachian Ridges, which so often appear in distant views as strikingly even-crested, upon closer examination are frequently found to be very much notched, due to erosion in post-Schooley time. Except in areas characterized by many ridges, the effects of Harrisburg erosion in the Southern Appalachians are more impressive than those of any other cycle.

TYPICAL HARRISBURG AREAS

In the following pages, some of the more typical and unique regions where the Harrisburg peneplane was developed between the Potomac and New Rivers will be described. It is not intended to be complete because that would involve too many details. A sufficiently large number of areas will be dealt with to bring out the essential nature of Harrisburg erosion, and to illustrate the present interpretation of such features in widely separated localities.

The Potomac Basin

Traces of the Harrisburg level are found along the valley of North Branch of Potomac River around Keyser, West Virginia, at an elevation of approximately 1000 feet. It also appears along the valley between Keyser, and Cumberland, Maryland, as well as in the valleys of tributary streams between Cumberland and Pawpaw, West Virginia. The basin of Evitts Creek just east of Cumberland preserves it fairly well.

One of the large areas of the Valley peneplane is in the Patterson Creek—Lunice Creek shale lowland which extends from the junction of Patterson Creek with North Branch of Potomac River, a few miles southeast of Cumberland, for a distance of forty-five miles to Petersburg, West Virginia. In fact, it extends somewhat south of the latter point. Lunice Creek flows southwest into South Branch of Potomac River at Petersburg, while Patterson Creek discharges to the northeast into North Branch. On the divide between these subsequent streams the Harrisburg surface is about 1400 feet above sea level and it slopes downstream in both directions. This valley is a pronounced intermontane lowland between Patterson Creek Mountain and New Creek Mountain (*Plate V*). It is represented on the Keyser and Greenland Gap, West Virginia, topographic maps.

Another magnificent development of the Harrisburg erosion surface occurs in the valley of South Branch above McNeill. It is shown on the Moorefield, West Virginia, quadrangle. The surface rises up Mudlick Run, a tributary of South Branch, to the Hampshire-Hardy County line where it attains a height of more than 1100 feet. From here it slopes down the valley of Mill Creek toward the north and forms the upland surface of a beautiful expanse of rolling topography between 950 and 1000 feet in elevation. This area is seen to good advantage along U. S. Highway No. 50 around Junction, seven miles west of Romney, West Virginia, and from this point south to Rada. This lowland almost unites with the Patterson Creek lowland previously described, but it is separated by a low divide on Patterson Creek Mountain, two miles northwest of Junction.

The belt of weak rock, on which the Mill Creek-Mudlick Run lowland is formed, joins the valley of South Branch at Old Fields, and continues upstream by Moorefield almost to Petersburg where South Branch cuts across the southern end of Patterson Creek Mountain. The Valley peneplane is marvelously well preserved up and down South Branch, and east of Moorefield River (South Fork). As already indicated, the peneplane is best preserved in shale areas, and because of the existence in these intermontane valleys of relatively broad belts of shale, especially the uniform Devonian shales, some of the finest Harrisburg areas in the Newer Appalachians are found here. The hilltops are notably accordant and their elevations increase quite uniformly upstream, as well as toward the bordering ridges. A typical view of the peneplane as it appears in South Branch valley is shown in Plates III and IV. The level is also extensively developed in the Petersburg area, and along tributary valleys which join the South Branch at this point.

The Romney area, type locality for the Romney shale, is also a region where the Harrisburg peneplane was typically developed. The belt of weak rock continues down the valley of South Branch from this point, and forms a broad lowland in which the stream has developed wide meanders. A large expanse of this lowland can be seen from U. S. Highway No. 50, especially from points to the east.

As one traverses the Appalachian Ridges between Winchester, Virginia, and Romney, West Virginia, he is traveling much of the time over the dissected Harrisburg peneplane. The ridges are relatively narrow, and the intermontane valleys, which preserve the Harrisburg, are broad. The rocks are closely folded so that a number of major folds as well as many minor flexures are seen. From Romney east to the Virginia-West Virginia line on Timber Ridge, it is approximately thirty miles. The region is drained by the northeast-flowing tributaries of the Potomac, the largest of which are Cacapon, North, and Little Cacapon Rivers. In the basins of all of these, the Harrisburg is easily seen. The widest expanse observed from U. S. Highway No. 50, lies between North and Little Cacapon Rivers. The peneplane is also broadly

developed in these shale belts where they are traversed by the Potomac River, as may be seen on the Pawpaw and Hancock quadrangles. An especially typical locality lies just east of Warm Spring Ridge and northeast of Berkeley Springs, West Virginia, where the erosion surface, except for the slight interruption of North Mountain, is really continuous with that of the Appalachian Valley. In fact, on the north side of the Potomac there is no break in the continuity of the peneplane from Hancock eastward to the open Valley around Williamsport, Maryland, where the surface is extensively developed between 500 and 600 feet. Like other estimates of this kind, the range of possible error is usually as great as 100 feet, except in those cases where the surface is remarkably well preserved in shale.

Campbell (*14*), while recognizing the downstream slope of the peneplane from Cumberland to Harpers Ferry, believes that it is due chiefly to deformation. He says, "From the above figures it is seen that this peneplain has a decided eastward slope from Cumberland to Harpers Ferry, and while it is certain that some of the slope is original and due to the grade of the stream while the peneplain was forming, it is probable that at least 90 per cent is due to subsequent deformation."

In later papers the same author has expressed the view that the Harrisburg (Chambersburg) peneplane, and the Bryn Mawr and Shepherdstown berms, come together in the fall zone region but separate with increasing vertical intervals toward the west. According to him the much deformed Harrisburg peneplane slopes steeply to the east, the next lower level, the Bryn Mawr berm, slopes less steeply, while the Shepherdstown almost parallels the present stream gradient. He would not assign the peneplane of the Harpers Ferry-Charles Town area to the Harrisburg, but possibly to the Bryn Mawr.

The Harpers Ferry Area

A typical development of the Harrisburg surface in limestone, centers around Charles Town, West Virginia, a few miles southwest of Harpers Ferry. Short tributaries flow eastward into the Shenandoah, while others flow westward into

Opequon Creek, a subsequent stream which empties into the Potomac. There are no monadnocks, and the valleys are not deep. It reminds one of some of the most perfectly peneplaned sections of the Piedmont. The divides are very low, and the surface is so flat that in places it is difficult to determine the drainage direction. The topographic aspect of the region is not youthful but rather that of subdued maturity. The general level of the peneplane around Charles Town is between 500 and 600 feet, while a few miles to the west it is a little higher. The 300 foot contour is crossed by the Potomac and the Shenandoah, a few miles up their respective valleys from Harpers Ferry. These streams are intrenched, therefore, somewhat more than 200 feet below the peneplane level. Furthermore, their valleys are bordered by steep walls. In view of the large amount of water which goes directly underground, this surface must have been reduced notably since the close of the cycle, but in general its flatness is remarkably well preserved.

Potomac River has carved a striking gap through the Blue Ridge at Harpers Ferry. The distance across the resistant rock belt below the junction with the Shenandoah is less than a mile, and the rapids are not impressive. Both the Potomac and the Shenandoah are sawing on crystallines before their united waters enter the gap. Short Hill parallels the Blue Ridge and lies several miles to the east. It really forms a part of the Blue Ridge barrier. Between the two ridges subsequent streams from the north and south flow into the Potomac. In Harrisburg time these streams developed surfaces corresponding to those in the Appalachian Valley to the west and the Piedmont to the east. The downstream slopes of these surfaces, however, are steeper. The same is true in other stream valleys such as Catoctin Creek in Maryland and the stream bearing the same name in Virginia. Especially typical portions of the Piedmont peneplane at elevations of approximately 500 feet are seen along the Harpers Ferry-Frederick highway in the vicinity of Petersville and Jefferson, Maryland, and again along the Berryville-Leesburg highway between Bluemont and Hamilton, Virginia. The Piedmont surface may be seen for long distances to the north and south of these highways.

So far as elevation is concerned, one could not expect to find anywhere a more perfect accordance than between the peneplane of the Piedmont and the peneplane of the Valley. In both cases they rise upstream, more rapidly along smaller streams, less rapidly along larger ones, and normally less rapidly in limestones than in crystallines. The depth of intrenchment of the major streams is similar on both sides of the Blue Ridge. The differences in degree of dissection of interstream areas also appear to be comparable when differences in rock type are taken into account.

The Winchester-Strasburg-Front Royal Area

This region is selected to illustrate several rather unique and distinctive characteristics of Harrisburg erosion. In general, the area surrounding the city of Winchester is characterized by evenness of hilltop at an altitude of approximately 800 feet. Near the eastern base of Little North Mountain, a few miles west of Winchester, the elevation is approximately 900 feet, while to the east, along the Shenandoah River, it is less than 600 feet. This difference of 300 feet in the elevations of different parts of the same peneplane, just fifteen miles apart, would seem unusual. It must be remembered, however, that the Harrisburg surface of the Winchester area was developed by *tributaries* of Opequon Creek, while Opequon Creek itself developed its Harrisburg surface as low as 600 feet. The lower part of Opequon Creek is a subsequent stream while the courses of its tributaries from the west, which developed the higher level, lie across the structure.

Just east of Winchester there is a broad belt of Martinsburg shale, which has preserved the Harrisburg level especially well, as may be seen in Plate VI. This shale belt extends southwestward under the North Fork of Shenandoah River, and the peneplane is notably well preserved along the Riverton-Strasburg highway at the north end of Massanutten Mountain. East of this shale zone, the subsequent Shenandoah River flows on a belt of limestones. The highway from Nineveh toward White Post follows pretty closely the boundary between shale and limestone. The even-topped hills of the shale country to the west contrast sharply with the eastward-sloping erosion surface to the

east. At some points, a rather distinct low escarpment separates the two. Unquestionably both of these belts were peneplaned in Harrisburg time. The shale area is in no sense a monadnock region, and the two belts illustrate very well the contrast between later erosion in shale and in limestone.

Another feature of this region is the valley of Passage Creek in Massanutten Mountain as shown on the Luray, Virginia, quadrangle. Massanutten Mountain, as a whole, is a rather complex syncline as described by Spencer (53). Powells Mountain and Three Top Mountain constitute a continuous ridge which forms the western rim near the northern end, while Massanutten Mountain is the eastern rim. Between these ridges lies an open valley which is known locally as Fort Valley. Passage Creek heads near the southern end of this valley and flows out at the north, discharging into North Fork of Shenandoah River. It has participated in the carving of the Harrisburg surface in shale where it emerges from the mountain near Water Lick. The elevation here is about 800 feet. In the middle part of Fort Valley, from Dilbeck to Edith, particularly in the vicinity of Fort Cross Roads, the Harrisburg surface was apparently developed. In some places there are fairly extensive remnants approximately 1200 feet above tide. They rise from 800 feet, where the stream emerges from the mountain, up to possibly 1300 feet at its southern end. In the narrow gorge through which Passage Creek flows as it leaves the mountain, there are graded, lateral slopes which lead down to a shoulder considerably above the present stream level. These graded slopes at least suggest the presence in the Harrisburg cycle of a mature valley. The traces are admittedly slight and it may be that all remnants of the former mature valley floor have been erased. With the exception of this locality there is a series of remnants rising upstream from Water Lick far into Fort Valley.

An interesting aspect of Harrisburg erosion is found in the valley of Gooneys Creek a few miles south of Front Royal, on the Luray quadrangle. This basin centers around Browntown and is developed on granodiorite of pre-Cambrian age. It is a cove surrounded on all sides, except the north, by the Blue Ridge Moun-

tain. The Harrisburg surface is only about 100 feet above the floor of Gooneys Creek and is preserved by accordant hills on both sides of the valley (*Plate VII*). It rises upstream, and averages approximately 950 feet in altitude in the neighborhood of Browntown, while beyond it reaches a height of at least 1000 feet. The uniqueness of Browntown Cove is not the perfection of the local peneplane, but the fact that it is developed on ancient crystalline rocks, and the further fact that the surface continues downstream to coalesce with the Harrisburg surface developed by South Fork of Shenandoah River on limestone and shale. Furthermore, this erosion surface is quite comparable to the numerous fingers of the Piedmont which protrude into the foothills along the eastern slope of the Blue Ridge as around Sperryville and Flint Hill.

The Upper Shenandoah Basin

The Valley peneplane characterizes the interstream uplands in the valleys of the North and South Forks of Shenandoah River (*Plate VIII*). West of Broadway, Woodstock quadrangle, where North Fork of Shenandoah River flows through Brocks Gap in Little North Mountain to enter the Valley proper, it is from 1200 to 1300 feet above sea level. It is easily traced upstream through the Brocks Gap country to an elevation of about 1700 feet at the Virginia-West Virginia line. From this point it rises slightly for about two miles toward the north in the direction of Mathias. North of the divide between North Fork and Lost River, it is developed with remarkable perfection. From an elevation of approximately 1750 feet opposite Mathias to 1700 feet opposite Lost City, it is an unusually even, gently sloping erosion surface on the west side of the valley.

From the vicinity of New Market, Woodstock, Virginia-West Virginia, quadrangle at an elevation of about 1000 feet, it rises to approximately 1400 feet at Harrisonburg on the divide between North and South Forks of Shenandoah River.

Although the belt of weak rock followed by South Fork is relatively narrow, the surface is traced with comparative ease from an elevation of approximately 700 feet at Front Royal to about 950 feet at Luray. The stream follows the eastern base of Mas-

sanutten Mountain. The Harrisburg surface rises slightly toward the western base of the Blue Ridge, but it never approaches the crest. Shallow sinks occur in considerable number along this valley, and there are occasional sink basins. There is an appreciable constriction of the valley between Rileyville and Bentonville, due to the westward projection of the Blue Ridge mass which includes the Erwin quartzite and other resistant formations on its western slope. Abundant stream-worn gravels were noted on hills around Bentonville, which may have been deposited by Shenandoah River late in Harrisburg or early post-Harrisburg time.

At Luray the peneplane is a little below 1000 feet. East of the city and partly within the city itself there seems to be a slightly lower level, perhaps 50 to 75 feet below the Harrisburg. It is restricted to the present valley of South Fork and is presumably a terrace. Such features are doubtless in some cases the valley floors of mature Harrisburg streams, which would be lower than the adjacent interstream areas. From Luray to Elkton, the Harrisburg is extremely well developed and it attains a height of approximately 1100 feet at the latter point.

A fairly perfect and typical section of the dissected Harrisburg peneplane is found in the area between Harrisonburg and the Shenandoah-James divide south of Staunton, Virginia. On this divide, the Harrisburg surface stands at present about 2000 feet above sea level. From this point it slopes down to the northeast to approximately 550 feet at Harpers Ferry. It descends toward the southwest to an elevation of 1000 feet where the James enters the Blue Ridge at Balcony Falls.

The James Basin

Typical localities of the Harrisburg surface in the upper James River basin are described in an earlier paper by the writer (*70*). The areas treated there include the Middlebrook region, ten miles southwest of Staunton, Buchanan region, fourteen miles southwest of Natural Bridge, Fincastle region, Gala region, and the Covington region.

Special interest attaches to the fact that James River developed

in Harrisburg time a surface which now stands about 1050 feet above sea level at Buchanan and 1000 feet at Balcony Falls. The area just west of its immediate valley was apparently drained to the southwest by a subsequent stream along the line of the old Plank Road, and to the northeast by other streams. Cedar Creek did not flow in its present position after leaving the Short Hills, but followed a more easterly course which led through the wind gap in Sallings Mountain. Its subsequent tributaries drained all of the area west of Natural Bridge, approximately as far south as the present county line, beyond which the drainage followed the line of the Plank Road to the southwest. Thus the Harrisburg surface in the region of the Natural Bridge is several hundred feet higher than the Harrisburg surface of the James River a short distance to the southeast. These conditions apparently provided the unique background for the later development of the present lower course of Cedar Creek, its gorge, and Natural Bridge itself.

Special attention should be called to the splendid development of the Harrisburg surface in the intermontane valleys of Catawba, Craig, and Potts Creeks, all of which enter the James or its upstream continuation, the Jackson River, within the limits of the Rockbridge quadrangle. These valleys are largely underlain by shale which accounts for the perfection of the peneplane.

A comparison of the elevations of the Harrisburg peneplane along the James River above and below its gorge through the Blue Ridge shows an accordance similar to that of the Potomac above and below Harpers Ferry. Just above Balcony Falls, remnants of the Harrisburg surface along the James and North Rivers occur at elevations ranging from 1000 to 1050 feet. Below the gorge, the Piedmont is well developed between Snowden and Big Island. Near the river, it has an altitude of 850 to 900 feet, while several miles away from the James, broad areas stand at an elevation of 1000 feet. One of the features of the Piedmont in this region is the occurrence of strips of Harrisburg surface extending up the streams among the foothills back to the very base of the main Blue Ridge.

The Roanoke Basin

The area of the Roanoke River basin is relatively small as compared with those of its neighbors. In the Harrisburg cycle it was even smaller than it is today. As explained in another section, most of the territory west of La Fayette which is drained at present by the two forks of Roanoke River was, in the earlier cycle, a part of New River basin. In spite of its small size, very typical areas of the dissected Harrisburg surface occur in the Roanoke-Salem area and extend upstream along Roanoke River to and beyond La Fayette, and along the tributary streams, Mason, Tinker, and Glade Creeks. From an elevation of 1060 feet around Roanoke, the erosion surface rises several hundred feet up these various tributary valleys.

The Roanoke area, furthermore, is a crucial district to show the relation between the Valley peneplane and the Piedmont peneplane. Except for a few low hills east of the city, the Blue Ridge is practically broken down opposite Roanoke City. There is no point along the valley of Roanoke River through these hills, which mark the position of the Blue Ridge, where there are not relatively broad areas at elevations ranging from 1000 to 1100 feet. The Piedmont peneplane to the east of the hills is extensively developed at an altitude of approximately 1000 feet. There seems to be no serious ground for questioning the continuation of the Harrisburg peneplane from the Valley into the Piedmont. The Valley and Piedmont peneplanes, on this interpretation, were produced in the same cycle.

The New Basin

The New River basin will be described briefly according to its natural subdivisions. There is the upper part in the crystalline highlands of western North Carolina and southern Virginia, a stretch through the Appalachian Valley, then a direct passage through the Appalachian Ridges, and finally a long course through the Appalachian Plateau.

A description of the valley of New River in the Older Appalachians is included in a paper by the writer entitled "The

Older Appalachians of the South" (*71*). It was pointed out how the record of Harrisburg erosion can be traced up New River as a local peneplane and finally as a mature valley. Its elevation at the northern margin of the crystalline belt, south of the Farmer Mountain-Poplar Camp Mountain ridge, is approximately 2500 feet, and it rises upstream to an elevation of about 3200 feet in the vicinity of Boone, North Carolina. In fact, traces of the mature New River valley of the Harrisburg cycle are found above Boone at increasing elevations.

The Valley peneplane surface is splendidly developed in the basin of New River around Pulaski at a height of 2200 to 2300 feet, and it slopes down to an elevation of about 2100 feet where the New enters the first of the Appalachian Ridges. In the area between Hoges Store and Pearisburg on the Dublin quadrangle, the Harrisburg peneplane is easily detected in spite of its deep dissection by an unnamed tributary of New River. Near Pembroke there are numerous rounded boulders resting upon the surface of a bench or terrace below the Harrisburg level. The boulders are abundant and overlie sink hole topography. Rounded boulders also occur on the west side of New River between Ripplemead and Pearisburg. They can be traced up to approximately the 1900 foot contour, but above that level they were not found. In the Pearisburg area the Valley level is about 2100 feet, while nearer the river it is perhaps as low as 2050 feet.

Just south of Narrows there are well-defined terraces, the highest one probably at least 100 feet above the present stream. The terraces of New River have been frequently mentioned by various workers but their origin has not been definitely settled.

North of Narrows, where the New has carved a picturesque gorge in Silurian quartzite, the stream enters the horizontally arranged sediments of the Appalachian Plateau. It is joined by Greenbrier River at Hinton, West Virginia, and finally at Gauley Bridge it unites with Gauley River to form Kanawha River.

The Greenbrier Basin

The Greenbrier basin lies between the Allegheny Front and the Appalachian Ridges. In the middle portion of this basin,

there is a broad expanse of limestone rock which was peneplaned in the Harrisburg cycle. Lewisburg, West Virginia, is located in the central part of this belt, and the region will be referred to as the Lewisburg Lowland. It extends for about fifty miles northeast and southwest with a maximum width of about ten miles. Between Marlinton on the north and Union on the south, this lowland is continuous, with the exception of the interruption caused by Droop Mountain. The Harrisburg local peneplane can be traced up the Greenbrier and its tributaries far beyond Marlinton, but it is only the broader area that will receive attention here. This region is unique in the fact that it lies west of all the true Appalachian Ridges but still within the area of folded rocks. The folding, however, is not as close as it is farther to the east.

The Lewisburg Lowland is not characterized by as even a surface as many of the Harrisburg areas. There are some localities, such as Little Levels around Hillsboro on the western side of the Marlinton quadrangle, where there is a strikingly even surface with elevations ranging from 2300 to 2350 feet. It is interesting to note that in this apparently almost perfect remnant of Harrisburg erosion there are no surface streams, all of the surface discharge passing off underground.

One of the impressive local features in this basin is the enormous development of limestone sinks. In the Sinks Grove-Pickaway-Union section, on the eastern margin of the Alderson quadrangle, the sinks appear in great numbers. The same is true around Lewisburg and also on both sides of the highway leading north from Lewisburg to Marlinton. A large sink basin west of Little Levels receives the waters of Hills and Bruffey Creeks and their tributaries. Certainly a very large part of the drainage in this region is underground.

Rather striking contrasts in elevation of Harrisburg remnants in nearby areas are found here. A good illustration may be seen in the Alderson region by comparing the elevation of the Union area, about 2100 feet, with that of the basin of Wolf Creek, six miles to the west, where the same surface has an elevation of about 1800 feet, in the neighborhood of Wolf Creek postoffice. As one travels

westward across the divide between these basins, several miles west of Sinks Grove, he looks down upon the lowland of Wolf Creek valley some 300 feet below the level of the basin to the east. By comparing the distance of these localities from Greenbrier River along the line of the natural drainage, it is easy to understand the main reason for the disparity in elevation.

There appear in this basin some rather striking contrasts between the expression of Harrisburg topography in shale and in limestone, where there are no differences in stream length. As in other similar regions, shale preserves more nearly than limestone the Harrisburg level. While it is difficult to generalize for the region as a whole, and quite impossible to be exact, the elevation of the peneplane is from 2100 to 2200 feet in the vicinity of Lewisburg, and it increases upstream to approximately 2500 feet at Marlinton.

An examination of topographic features between the Allegheny Front, west of Lewisburg and Marlinton, and the Appalachian Ridges east of the Greenbrier River, brings out the fact that there is a bench east of the scarp intermediate in elevation between the scarp and the Harrisburg peneplane. The elevation of the scarp is approximately 4000 feet, being somewhat lower west of Lewisburg than in the area near Marlinton. It is a well-known fact that it becomes lower toward the southwest from its maximum elevation in the Durbin region. The Harrisburg surface in this basin as already noted, does not rise appreciably above 2500 feet. The intermediate bench is especially well-developed at an elevation slightly above 3000 feet on Droop Mountain which notably constricts the Greenbrier Valley twenty miles north of Lewisburg, West Virginia. The highway between Marlinton and Lewisburg traverses this level mountain summit for a distance of about four miles. The same elevation is found farther south on Brushy Mountain and on Brushy Flat. Northwest of Clintonville lie the open valley heads and broad valley floors of Otter Creek and other streams which form Meadow River. These streams drain an area whose interstream elevations are fairly uniform between 2600 and 2800 feet, which is distinctly below the much dissected scarp to the north and northwest. These features are portrayed on the

Clintonville, West Virginia, quadrangle. Sinking and Hughart Creeks have developed what may be the Harrisburg surface on a limestone belt in the eastern part of the quadrangle.

The Clintonville map depicts a very interesting area, more interesting than understood. There are at least four different groups of topographic features. In the northern part, the much dissected Allegheny scarp, represented by Buffalo Mountain and Cross Mountain, reaches a maximum height of 4050 feet; the central two-thirds of the map is characterized by the intermediate bench at an elevation of 2600 and 2800 feet; in the extreme southeastern corner there is a bend of Greenbrier River bordered by a strip of Harrisburg surface about 2000 feet in elevation; lastly, Sinking Creek and its tributaries have developed a level of approximately 2200 feet in altitude just north of U. S. Highway No. 60. While the Allegheny Front with its fairly even skyline is usually regarded as a remnant of the Schooley, it may represent a low cuesta-like monadnock on the Schooley level. If this is true, the elevation of the Schooley is lower than the maximum elevation of the scarp. The intermediate bench described above as most typically preserved on Droop Mountain is probably due largely to the horizontal structure. It is not underlain entirely by the same rock formation, but sandstone and sandy shale seem to predominate. They are not as massive, and presumably not as resistant, as the sandstones and conglomerates that underlie the scarp. The limestone and shale belt in the eastern part of the area was certainly peneplaned, but its low altitude at the present time may have been caused in large part by solution. If these observations are correct, there are in this region some very striking illustrations of the effects of differences in rock resistance.

Post-Harrisburg Cycle[3]

GENERAL STATEMENT

The post-Harrisburg cycle began with the uplift of the region which probably occurred late in the Tertiary period. Although a relatively short period of time has transpired since its inauguration, a large amount of erosive work has been accomplished. The normal depth of dissection by the streams varies from several hundred feet, in downstream situations, to almost nothing at the heads of the valleys, where the streams are flowing near their Harrisburg levels. Greater depths of dissection than these are found in those areas where stream piracy has occurred since the close of the Harrisburg cycle.

The stage of development of the present stream valleys varies from youth to maturity, depending upon the size of the stream, and the nature of the underlying rocks. Modern flood plains with broad meanders are found along the courses of some of the master streams. The most youthful conditions are found farther upstream but not at the valley heads. The characteristics of early youth are exhibited by those streams which have been involved in drainage changes, as shown in Plate XVIII.

STREAM TERRACES

The post-Harrisburg cycle is characterized by the formation of terraces in many different localities throughout the region. They are found along the Shenandoah, James, Roanoke, and New River valleys. Some are flood plain terraces which require no special explanation, while others are rock terraces covered by a veneer of stream gravels and boulders. So far as the writer is aware, these features are restricted to valleys and have no representation in the interstream areas.

In a general way these terrace levels may be thrown into two groups, an upper and a lower series. Of the former, there are

[3] The post-Harrisburg cycle may have been broken by uplift into two or more partial cycles. Until it is possible to demonstrate the existence of land forms that were produced during such partial cycles the present writer prefers to treat it as a unit.

many examples. Some of the most typical representatives of the upper group are along New River between Dublin and Pearisburg, along Craig Creek in the western part of Eagle Rock quadrangle, and along James River between Buchanan and Natural Bridge Station. They are found in the valley of almost every intrenched meandering stream in the region. These benches, oftentimes preserved on the surfaces of intermeander spurs, are typically flat and frequently carry stream-worn gravels and boulders. They occur as much as a hundred feet below the level of the Harrisburg peneplane on the adjacent valley walls.

The lower group of terraces is associated with the valley floor and the lower slopes of the valley walls. Both flood plain terraces and hard rock terraces are represented, the former being restricted to the lowest of the group. They range in elevation from ten feet to more than one hundred feet above the present flood plain. Stream-worn boulders are commonly found on their surfaces. Many of these terraces are very distinct features of the valley floors. The best examples, so far as the writer has observed, are found in the upper James River basin where there are excellent illustrations of rock terraces covered with gravel. (*Plate IX.*)

The problem of the origin of these terraces merits further study. Efforts to correlate those of the James River basin were made by the author as described in an earlier report (*70*). Correlation in many places was not possible, and hence they were probably not produced by successive uplifts. In some instances, they doubtless owe their existence in part to the presence of a resistant upstream rock defense. It is possible, even where the material is bed rock, for a more sandy and massive portion of the rock formation to "defend" the softer shale downstream. These rock terraces are restricted to shale valleys.

The higher group of terraces is tentatively assigned to the flood plains of Harrisburg time. There is apparently no well-attested case where more than one high terrace occurs in the same locality. The explanation seems particularly applicable to those cases where the broad strips of gravel-covered terrain form the surfaces of intermeander spurs. It is not reasonable to expect the areas bordering the stream to have been brought as low as the valley

floor in the Harrisburg cycle. At the close of this cycle, the valley bottoms could easily have been fifty or even a hundred feet below the erosion level of the surrounding region. The second group, associated with the valley floor, are apparently the details of valley formation in recent geological time.[4]

DISSECTION OF INTERSTREAM AREAS

The erosion of interstream areas of the Harrisburg peneplane in the post-Harrisburg cycle varies in both nature and extent. It should be borne in mind that the Harrisburg surface was developed almost entirely on limestone and shale in the Newer Appalachians. These rocks for the most part offer only moderate resistance to erosion. At the same time there are tremendous variations among these so-called weak formations. Shale is generally weak physically but strong chemically. Limestone, on the other hand, resists mechanical erosion rather well but is chemically weak. These two statements are subject to as great variation as there are variations in the composition of limestone and shale. It is not unusual to find two limestone belts lying side by side which exhibit striking contrasts in both the nature and the extent of post-Harrisburg erosion. In order to show the contrast between the topographic expression of shale and limestone and to point out some of the problems involved in the interpretation of the erosional history of post-Harrisburg time, several typical areas will be described.

Area South of Winchester, Virginia

A broad belt of Martinsburg shale extends southwestward from the Potomac River to the northern end of the synclinal Massanutten Mountain where it passes under and entirely surrounds the mountain. Typical sections across this belt are traversed between Winchester and Berryville, between Winchester and Boyce, and still farther south between Stephens City and White

[4] The fact that the terraces seem to fall into two groups, an upper and a lower, suggests the possibility of correlating them with the features along the Potomac River described by Campbell (*17*). He calls the upper level the Bryn Mawr berm, and the lower, the Shepherdstown berm.

Post. The western border of the shale belt lies just east of the Lee Highway while the eastern boundary is west of Berryville, Boyce, and White Post. It is four to six miles in width and is bordered by limestone on either side.

The topography of the shale belt is typical for shale regions. Near the streams there is sharp dissection, with very steep, smooth valley sides and flat interstream areas. As a whole, it is beautifully peneplaned, and the peneplane is preserved on most of the hilltops. A typical view is shown in Plate X. Coming to the eastern border, about two miles west of White Post, one notes that the hilltop level which had hitherto been sloping very slightly to the east, makes a rather sudden change and the degree of slope is greatly increased. The limestone belt to the east seems to be at least seventy-five feet below the almost level shale upland to the west. There are numerous sinks in the limestone area and much of the discharge passes off underground. There are also many rock outcrops, the slopes are less regular, and the valleys are much shallower than in the shale country to the west. The aspect of the topography is more mature here, and while the country is not characterized by perfect flatness, it has the general appearance of a peneplane. It is unlike the peneplane in the shale country where the hilltops are more accordant, and the dissection deeper.

From a point five miles north of Riverton on the road to Berryville, excellent views may be had of the contact between the well-preserved peneplane on the accordant shale hills to the west, and the lower surface on limestone to the east. The limestone surface slopes eastward toward the Shenandoah River. Photographs looking west and east from this highway are seen in Plates XI and XII. There are two levels separated by a scarp, the upper on shale, the lower on limestone. The question as to whether or not they represent two cycles of erosion or different aspects of erosion in the same cycle has not been settled.

Area South of Harrisonburg, Virginia

At the south end of Massanutten Mountain, the same belt of Martinsburg shale, which lies between Winchester and Berryville,

continues as above. West of Port Republic, Harrisonburg quadrangle, the Harrisburg peneplane is splendidly developed on shale at an elevation of about 1200 feet. To the east and the west of the shale belt the peneplane is developed on limestone at elevations slightly less than that on shale. This is particularly true of the limestone belt to the east. Still farther to the west there are linear monadnock ridges on cherty limestone, such as Chestnut Ridge east of Harrisonburg.

The broad meanders of Middle River southwest of Port Republic are on the southward extension of this belt of Martinsburg shale. The widest meander belts in the Southern Appalachians are very frequently found in shale.

Area Around Union, West Virginia

One of the best regions in the Newer Appalachians for the study of erosion in limestone lies between the Allegheny Front and the Appalachian Ridges. It extends from Marlinton, West Virginia, to Lewisburg, and on toward the New River. One of the choicest areas in this belt centers around Union. It is depicted on the Alderson, West Virginia, quadrangle. Limestone sinks are extremely abundant here and also in the neighboring locality to the north called Sinks Grove. It is really honeycombed with sinks, and well peneplaned.

From Hillsdale, on the western margin of the Ronceverte quadrangle, one can look west across the Pickaway limestone belt, a region 100 feet or more lower than the shale country immediately surrounding him. While the lower surface does not appear more even than the upper, it has been reduced especially by solution. There is no exterior drainage, the water all passing out through the numerous sinks. The photographs in Plates XIII and XIV bring out the contrast in elevation of the two areas.

The above three illustrations are sufficient to indicate the nature of the problem. Shale areas seem to preserve much better than limestone areas, the Harrisburg peneplane. In view of the very large amount of subterranean drainage, it would seem that limestone areas must be lowered more rapidly than areas underlain by rocks that are less soluble. A part of the work of solution is certainly accomplished near or at the surface.

An area such as Little Levels, located on the western margin of the Marlinton quadrangle, illustrates the case in point. There are no surface streams in this locality in an area of more than a dozen square miles, except short temporary streams which empty into sinks. Nevertheless this region is one of remarkable evenness of surface. It is obviously not a surface that has been worn by mechanical means but rather one that has been lowered evenly through solution.

In various localities in the Southern Appalachians, the writer has taken special note of the Harrisburg peneplane as it is expressed in shale and limestone areas. In some cases the limestone topography is quite rough due to the effects of differential solution, especially where cherty and other resistant layers alternate with more soluble beds. In some cases the shale areas have eminences due to the presence of sandy layers. Eliminating variations within the shale on the one hand and the limestone on the other, it is rather generally true that the present surface level on limestone areas is lower than that on the adjoining shale areas. Sometimes the difference is slight, while in other places there is a contrast in elevation of 200 or even 300 feet, where very soluble limestone comes in contact with resistant, uniformly bedded shale. Ordinarily the lowest limestone areas are relatively small, and rather definitely related to the lithology and structure.

THE PROBLEM OF THE SOMERVILLE AND OTHER POST-HARRISBURG PENEPLANES

As is well-known, different workers in the Northern as well as in the Southern Appalachians have found one or more peneplanes below the Harrisburg. With the possible exception of the Somerville they are mostly restricted to valleys, or to benches which are not traced far from the main streams. Features that might be interpreted as remnants of later peneplanes are found in different parts of the area under consideration, but more especially in the drainage basin of the Tennessee River and its tributaries. The James River valley between Buchanan and Balcony Falls is also a case in point. The fact that the present valley walls in many cases do not rise as high as the peneplane level a mile or so from

the stream, does not appeal to the writer as sufficient evidence to justify the introduction of a distinct erosion cycle to account for the lower elevations along valley walls. The development of a surface having lower elevations near the streams depends somewhat upon the character of the rock as well as upon the structure.

Perhaps the most suggestive traces of a post-Harrisburg level are found in the high terraces along the James, the New, and other streams. An explanation tentatively offered by the present writer is that they may represent remnants of Harrisburg valley floors. It would not seem unreasonable to expect that with continuous downcutting there should be left gravel-covered remnants of flood plains and shoulders even below the bottoms of Harrisburg valleys. These features are not remnants of a peneplane but rather like the berms described by Campbell (*17*). They have no recognizable expression in interstream areas.

In the preceding paragraphs, the writer has described areas of limestone which have been reduced lower than other parts of the Harrisburg surface underlain by shale. In many cases these belts trend with the strike of the rock, and their size is obviously determined by the extent of highly soluble rock. Since the interstream surfaces below the Harrisburg are largely restricted to highly soluble limestone, the writer suggests that they may have been lowered uniformly mainly by solution. The process has been particularly effective in those regions where there is little surface discharge, and it is obviously still in operation. If the hilltops had been reduced chiefly through solution, the surface would have maintained a fair degree of evenness from the beginning of post-Harrisburg time until the present. Such a surface is not a peneplane in the original sense of the term, as defined by Davis, because it does not mark the completion of a cycle or even a partial cycle.

An interesting aspect of valleys in shale is the elaborate development of meanders, many of them intrenched, in the longitudinal shale belts of the Appalachians. These include the most striking meanders of the region. They are unique in their width as well as in the number of meanders in a series. Some of the best examples are those along Potomac River northeast of Pawpaw, West

Virginia; along North Fork of Shenandoah River between Woodstock and Strasburg, Virginia; along South Fork of Shenandoah River between Luray and Front Royal, Virginia; along Middle River just east of Mt. Sidney, Virginia; and along Craig Creek between Newcastle and Horton, Virginia. In some of these valleys, the shale includes some sandy layers, and the meanders sometimes encroach upon limestone belts. Nevertheless, shale is the dominant rock in the above valleys as well as in many others where broad meanders occur. The physical weakness of shale may be partly responsible for the width, symmetry, and length of these meander belts.

Regional Drainage

GENERAL STATEMENT

Including the Potomac, there are five major streams in the Newer Appalachians of the South (Fig. 1). From north to south they include the Potomac, James, Roanoke, New, and Tennessee Rivers. The areas of the several drainage basins vary considerably in size, the Roanoke being the smallest (388 square miles above Roanoke, Virginia), and the Tennessee the largest (21,400 square miles above Chattanooga, Tennessee). Two of these streams, the Potomac and the James, have been superposed across the Appalachian Ridges and also across the Blue Ridge. The Roanoke has really experienced no superposition. It does not flow across a single member of the Appalachian Ridges and its passage through the Blue Ridge is accomplished by favorable structural conditions which have largely eliminated resistant rocks. New River is either a powerful antecedent or it has been grandly superposed across both the crystallines and the folded sedimentary rocks. Except for its crossing Walden Ridge near Chattanooga, Tennessee River does not at present occupy a superposed position. Many of its tributaries, however, such as the Hiwassee,

the Little Tennessee, the French Broad, and the Nolichucky, flow across the trend of the crystallines and to a lesser extent across the minor ridges of the Appalachian Valley.

It will thus be seen that any adequate hypothesis for the present courses of the main streams of the Southern Appalachians must provide for a southeastward superposed course for the Potomac and James, for no superposition in the case of the Roanoke, for the northwesterly course of the New, and for an enormous development of major and minor subsequent drainage lines in the Tennessee basin.

The writer has no hypothesis to offer for the courses of these master streams. In the following paragraphs, he would like to point out some of the most significant examples of superposition in this region and to indicate the position of a possible divide between streams that were superposed to the east and those whose superposed courses were toward the west. He does not have sufficient evidence to justify a discussion of the hypothesis of regional superposition from a surface older than the Schooley, as set forth by Johnson (*38*), or the earlier theory of Davis, (*23*) and others.

THE POTOMAC BASIN

North Branch of Potomac River flows out of the Appalachian Plateau through a gorge west of Keyser, West Virginia. In the lower part of its thirty-five mile course through the Plateau, it has splendid entrenched meanders. The stream level is nearly 1000 feet below the plateau surface and its serpentine valley is one of the grand gorges of the Appalachian Highlands.

The first important ridge to be crossed by North Branch is Knobly Mountain at Cumberland, Maryland. It is the northward continuation of the anticlinal New Creek Mountain which has been so beautifully bisected by streams flowing through Greenland, Cosner, and Kline gaps as shown on the Greenland Gap quadrangle. A view of Greenland Gap is shown in Plate XV. The courses of these streams across the New Creek Mountain anticline are difficult to explain on any ground other than superposition. There does not seem to be any well-attested case in the

Appalachians where in a normal cycle a lateral consequent stream has grown by headward erosion across an anticlinal arch. Special significance attaches to this case of superposition because it involves the first arch east of the Allegheny Front. It seems, therefore, that whatever the agency of superposition, it must have been operative at least as far west as the Allegheny Front in the upper Potomac Basin.

Wills Creek has an obviously superposed course across Wills Mountain just west of Cumberland. A splendid arch is exposed in this water gap. Further evidence of former transverse drainage across this fold appears in the wind gap in Wills Mountain near Allegany Grove, a few miles southwest of Cumberland.

The course of the Potomac below the junction of North and South Branches near Green Spring, West Virginia, cuts directly across some ridges such as Sideling Hill, while in other places as near Pawpaw, West Virginia, it flows in a broadly meandering subsequent course. At Harpers Ferry it breaks through the Blue Ridge.

Before leaving the Potomac Basin, reference must be made to the series of wind gaps in the Blue Ridge between the Potomac and the James. Beginning at the north, the most prominent of these are Snickers (1150 feet), Ashby (1050 feet), Manassas (950 feet), Thornton (2279 feet), Swift Run (2350 feet), and Rockfish (1850 feet). In addition, there is one very low gap in Massanutten Mountain which lies in the Shenandoah Valley to the west.

The floors of these gaps are from 800 to 1000 feet below the crest of the Blue Ridge and consequently form natural passageways across the mountain. Paved highways lead through most of them. Their transverse profiles are entirely normal for stream valleys. The writer has been unable to find stream gravels on the floors of these gaps, but they could not be expected to remain there during the long period of time since the streams which occupied them took other courses.

These gaps are as strongly indicative of superposition across the Blue Ridge as the present water gaps of the Potomac and the James. Many years ago Willis (*68*) explained the capture of Beaverdam Creek by Shenandoah River which grew southward

as a subsequent tributary of the Potomac along the west base of the Blue Ridge. This has come to be one of the classical examples of stream piracy in this country. Beaverdam Creek and Potomac River were competing streams flowing across a resistant barrier, the Blue Ridge, the former at Snickers Gap and the latter at Harpers Ferry. Behind the Blue Ridge lay a belt of weak limestones. By reason of the greater volume of the Potomac, and possibly the greater resistance of the barrier at Snickers Gap, the Potomac was able to cut down more rapidly than Beaverdam Creek. This enabled the Shenandoah to tap the latter on the west side of the Blue Ridge. Eventually the Shenandoah robbed the other transverse streams and brought the drainage of the entire Shenandoah Valley, and of the Ridges immediately to the west, into the basin of the Potomac.

Watson and Cline (*66*) have attempted a rather complete restoration of the drainage history of the Shenandoah and its tributaries. They stated that during a large part of the "Tertiary cycle" there were three main transverse stream systems including the Potomac. Goose Creek flowed through Manassas Gap and carried out the drainage of the Massanutten Mountain area. Another stream, Rockfish River, led the drainage of the upper Shenandoah Valley through Rockfish Gap. Late in this cycle Goose Creek captured Rockfish River so that all of the drainage of the Shenandoah Valley region south of Front Royal was carried by Goose Creek through Manassas Gap. With the inauguration of the "Shenandoah cycle," Goose Creek and the Potomac were the rival drainage systems in the Valley. Early in this cycle, Shenandoah River captured Goose Creek and thus completed the series of major changes, as outlined by these authors, which resulted in the present system.

Perhaps the most impressive alignment of wind gaps and stream courses is near New Market and Luray, Virginia. North Fork of the Shenandoah heads in the ridges west of Brocks Gap and flows eastward to New Market, just west of the low New Market wind gap in Massanutten Mountain. Thornton Gap in the Blue Ridge is in direct alignment with the gap in Massanutten Mountain and also with the upper part of North Fork of the

Shenandoah. Thornton River rises against the east slope of the Blue Ridge at Thornton Gap, and marks the lower course of a former stream which flowed through the New Market and Thornton Gaps.

A further fact of interest in this connection is the synclinal structure of Massanutten Mountain. The ancient river referred to above flowed across a major syncline and in doing so demonstrated its true superposed nature. Among the transverse streams across the Blue Ridge, this one points most clearly to an earlier superposition. Synclines, like anticlines, are not bisected by streams in the normal development of drainage lines.

THE JAMES BASIN

The upper stem of the James is known as Jackson River as far down as its junction with the Cowpasture River below Clifton Forge, Virginia. Jackson River heads near Monterey, Virginia, flows southwestward as a subsequent stream to Covington, and thence eastward through a partly subsequent course to Clifton Forge. Back Creek, an important tributary of Jackson River, has its source in a narrow monoclinal valley between Lantz and Allegheny Mountains in the northern part of the Monterey quadrangle. It flows southwestward for a distance of thirty miles and receives numerous tributaries from the east and west. Then it takes a more southerly course across the Back Creek Mountain anticline to join Jackson River. The topographic features at this junction are clearly represented on the newly published Mountain Grove, Virginia-West Virginia, quadrangle.

The superposition of James River across the Rich Patch Mountain anticline at Clifton Forge is one of the outstanding features of the Appalachians. Its special significance consists in the fact that there is exposed in the gorge at Iron Gate one of the great anticlines of the East. A view of this gap is shown in Plate XVI. The case for superposition across this plunging fold seems so obvious that a review of the regional history would be superfluous. From Iron Gate to Balcony Falls, where the James enters its gorge in the Blue Ridge, the stream has for the most part a subsequent course. One marked exception is at Eagle Rock, on the

Rockbridge quadrangle, where the stream has cut a gap between Crawford and Rathole Mountains.

The divide between James and Greenbrier Rivers follows the crest of Allegheny Mountain, four or five miles west of the main stem of Back Creek. The Greenbrier, and its tributaries, occupies the territory between Allegheny Mountain on the east and the Allegheny Front on the west. Therein lies a difference between the James and the Potomac basins, for the Potomac drains a considerable section of the Appalachian Plateau.

As is commonly known, the divide between the James and the Potomac is asymmetrical, the northward flowing tributaries of the Potomac being much longer than the southward flowing tributaries of the James. The probable explanation of this fact is differential uplift which took place at the conclusion of the Schooley cycle and perhaps to a slight extent also at the close of the Harrisburg cycle.

THE ROANOKE BASIN

Roanoke River has two forks, North and South. The latter rises just west of the Blue Ridge scarp in the crystalline area of the Older Appalachians, while the former heads in the Appalachian Ridges to the north. The basins of these two streams apparently were drained in Harrisburg time by tributaries of New River. The drainage modifications that have been involved in this region are described in another section of this paper. Below the junction of North and South Forks at La Fayette, the Roanoke proceeds as a subsequent stream to the break in the Blue Ridge where it enters the Piedmont. The writer finds no evidence of superposition in the present course of this stream. Furthermore, there is no impressive evidence in the form of wind gaps to indicate that prior to the development of a considerable number of subsequent streams in the ridges to the northwest, there were important transverse drainage lines. Mason Creek, which enters Roanoke River just east of Salem, might conceivably mark the position of a one-time larger stream whose course was inherited from an overlying cover.

The subsequent drainage lines of the northern part of the

Christiansburg quadrangle are unique in that their discharge is distributed among three major rivers, the James, Roanoke, and New. Beginning at the northwest, North and South Forks of Potts Creek unite to flow northeastward in a subsequent valley for a distance of thirty-five miles before entering Jackson River at Covington. Johns Creek in the next valley flows twenty-five miles northeast to join Craig Creek at Newcastle. Craig Creek continues another twenty miles to join the James at Eagle Rock. Between Johns Creek and Craig Creek, Sinking Creek flows to the southwest into New River. In the valley southeast of Craig Creek, North Fork of Roanoke River discharges to the southwest, and Catawba Creek toward the northeast into the James. No special significance is attached to these relationships in spite of the fact that the area seems to occupy a strategic position between the James, which was superposed to the southeast, and the New which may have been superposed to the northwest.

THE NEW BASIN

New River is one of the most interesting of Appalachian streams. Its head is near Blowing Rock at the edge of the Blue Ridge escarpment in western North Carolina. It flows northeastward for a distance of seventy-five miles before it enters the Appalachian Valley southeast of Wytheville, Virginia. Its subsequent course along the floor of the Valley continues for thirty miles to Radford, Virginia. Here it turns northwest across the Valley and the Appalachian Ridges into the Appalachian Plateau. Its gorge through the Ridges is picturesque, especially at Narrows, where it flows through the gap between Peters and East River Mountains. Because of the fact that it flows from the Older to the Newer Appalachians, in the direction in which the Paleozoic streams flowed from ancient Appalachia to the interior sea, this river may have maintained an antecedent course since the Paleozoic Era.

It may be difficult to find positive evidence against the idea of antecedency, but to say the least, it is highly improbable. The great length of time since the Paleozoic, involving a considerable number of cycles and partial cycles of erosion, separated by re-

gional uplifts and warpings, seems to render the suggestion most improbable if not impossible. Furthermore, Paleozoic seas with their sediments may have covered large parts of the crystalline areas. If, as Johnson (*38*) suggests, the Appalachians were in Mesozoic time partly buried beneath a thin cover of marine sediments, the continuity of the supposed antecedent New River would have been broken.

Although it has the direction of flow which Paleozoic streams must have had, it seems that there are other possibilities which are more apt to be correct than the idea of antecedency. It would be wiser to try to find an explanation for the course of New River in the events of its later history rather than in the remote period when the sediments of the Appalachians were being deposited.

THE GREENBRIER BASIN

One of the large tributaries of New River is the Greenbrier. Its peculiar position in reference to other drainage lines may throw some light on the history of the regional drainage. Greenbrier River rises north of Durbin in Pocahontas County, West Virginia, and flows southwestward for a distance of a little more than one hundred miles to Hinton, West Virginia, where it unites with New River. Through much of its length it is a subsequent stream following a very direct course a short distance east of the Allegheny Front. It will be remembered that this portion of the Allegheny escarpment is a pronounced feature. For a distance of nearly thirty miles Shavers Fork of Cheat River, which is flowing opposite in direction to the Greenbrier and on the Appalachian Plateau to the west, parallels the upper part of the Greenbrier. As one follows the old Staunton-Parkersburg pike from Durbin northwest to Cheat Bridge, he crosses the south-flowing Greenbrier at Durbin, ascends the steep east-facing Allegheny escarpment, then proceeds down the open valley of Blister Run to cross the north-flowing Shavers Fork at Cheat Bridge. By airline the Greenbrier is just three miles east of Shavers Fork at Cheat Bridge.

The course of Greenbrier River and the associated topographic

features may be traced by examining the following topographic maps of the U. S. Geological Survey: Durbin, Cass, Mingo, Marlinton, Huntersville, White Sulphur Springs, Ronceverte, Alderson, and Big Bend. All of these quadrangles lie within the State of West Virginia, with the exception of Cass and Ronceverte which include small sections of Virginia. The Huntersville map has a scale of two miles to the inch, while the remainder are the more recent fifteen minute maps.

The Greenbrier is the most westerly of the series of subsequent streams in the Appalachian Ridges west of Staunton, Virginia. The most important ones are the Calfpasture, Cowpasture, and Jackson Rivers, Back Creek, and the Greenbrier. There is just one tributary of the Greenbrier coming in from the east that deserves special notice. This is Knapp Creek near Marlinton, West Virginia. About seven miles east of Marlinton, Knapp Creek has cut through the anticlinal arch of Marlin Mountain-Brushy Mountain (*Plate XVII*). The stream is flowing to the west, and if the present interpretation is correct Knapp Creek must have been superposed across this barrier.

This case of superposition is particularly suggestive in view of the fact that it is less than a dozen miles northwest of the point where the east-flowing Back Creek has been let down upon the Back Creek Mountain anticline. These facts indicate that the surface upon which superposition took place must have descended both to the east and to the west, and that the divide must have stood somewhere near the present divide between the Greenbrier and Jackson Rivers on the crest of Allegheny Mountain. This is also the boundary between the states of Virginia and West Virginia.

Turning to the west side of the drainage basin of the Greenbrier, it will be observed that the lateral tributaries are even shorter here than on the east. In common with many other subsequent streams, the Greenbrier has a long narrow basin with many small but few large tributaries. The arrangement of the neighboring streams to the west is particularly noteworthy. Reference has already been made to the northeasterly course of Shavers Fork of Cheat River. Next in order comes the Tygart whose general

direction is toward the north. The Little Kanawha, Holly, Gauley, Williams, Cranberry, Cherry, and Meadow Rivers flow in general toward the west from the central higher part of the Appalachian Plateau. The highest part lies just southwest of Durbin along the Allegheny escarpment where there are elevations slightly above 4800 feet. A somewhat more detailed description of these drainage lines may be found in an earlier paper by the writer (*70*). Considerable emphasis was placed upon regional warping as well as upon local doming. The latter may have been carried a bit too far, but the general facts of differential uplift of the Upland peneplane seem to be verified by later study.

If superposition has occurred as proposed by Johnson (*38*), it must have taken place prior to the Schooley cycle. It is probable that the great development of subsequent drainage took place during the Schooley and to some extent during the Harrisburg. Many of the wind gaps of the region are too shallow to provide a very reliable basis for a reconstruction of the superposed stream lines.

A gap of sufficient size to justify special attention occurs in the eastern escarpment of the Appalachian Plateau just northwest of Durbin, West Virginia. Blister Run heads near the gap and flows northwestward into Shavers Fork. The floor of the gap has an elevation of approximately 3750 feet, while the escarpment on either side is approximately 4450 feet above sea level. A splendid view of this broad notch may be had from the highway where it crosses the mountain just west of Cheat Bridge. If this is a true wind gap, as it appears to be, it raises the question as to what stream formerly occupied it and the direction of its flow.

It may be well to bear in mind the fact that the Allegheny Front offsets to the east in this locality. The Greenbrier basin occupies an anticlinal belt between the Back Allegheny Mountain (Allegheny Front) and the Allegheny Mountain on the east. The folding dies out at the north and the plateau topography continues on to the east so that Allegheny Mountain really becomes the Allegheny Front. Various local names are applied to this feature such as Spruce Mountain, which is surmounted by Spruce Knob (4860 feet), the highest mountain in West Virginia. On the

Spruce Knob map one can detect some structural trends in the topography but it is distinctly more like plateau than folded mountains.

If the divide between east-flowing and west-flowing superposed streams did follow in general the present Allegheny Mountain crest, as suggested above, we should expect to find some outlet to the west for the discharge of the plateau area now drained by East and West Forks of Greenbrier River. The former drains the southwestern fourth of the Spruce Knob quadrangle and flows westward to join West Fork at Durbin. The lower course of East Fork may indicate the position of an earlier stream which continued to the northwest through the low sag in the Allegheny escarpment to join Shavers Fork in the vicinity of Cheat Bridge.

The apparent superposition of Knapp Creek across the anticlinal structure of Marlin Mountain-Brushy Mountain, referred to above, would require a westerly continuation of its course beyond the present subsequent Greenbrier. A study has been made of the scarp west of Marlinton to determine a possible position for a former stream. Such a situation seems to exist at the head of Laurel Creek in the southern part of the Mingo quadrangle. The exact position is marked by the Woodrow School near which is a bench mark indicating an elevation of 3210 feet. The valley of Laurel Creek is strikingly flat-floored and open. About the only evidence in favor of the above interpretation is its alignment with the possible continuation of the former Knapp Creek, and its transverse profile. There are no rounded gravels or other evidences of a former stream that the writer could detect. It is obvious, of course, that the great amount of erosion that has gone on since the suggested diversion took place would have erased all minor evidences of stream diversion.

Between the East Fork of the Greenbrier River and Knapp Creek, both of which may be parts of west-flowing superposed streams, there is a slight suggestion of a former stream course in a sag in the scarp east of Shavers Fork in the northwestern corner of the Cass, Virginia-West Virginia, quadrangle. Leatherbark Run, a tributary of the Greenbrier, is gnawing into the escarpment so effectively that its capture of the headwaters of Shavers Fork

is imminent. The elevation of the scarp at this point is just 3940 feet, while on either side the knobs rise to more than 4800 feet. This low divide may have been produced by the dissection of the present streams, but its position northwest of the west-flowing Sitlington Creek is faintly suggestive of a former stream course in this position.

Otter Creek and Meadow River, on the Clintonville, West Virginia, quadrangle, have especially broad valley floors which may have some relation to earlier transverse drainage. If such is the case, the streams must have persisted well into the Harrisburg cycle because the elevation of the flat-floored basin is much below the present Schooley. The explanation of these open valleys, and of Cranberry Glades, in the broad valley head of Cranberry River, Lobelia, West Virginia, quadrangle, is not clear to the writer.

The Greenbrier River is at present a subsequent stream, and like other subsequents it developed its course only after deep erosion had exposed weak rock. The evidence cited above suggests that the drainage which it now carries to the southwest formerly flowed northwestward through several transverse streams, including one at Durbin, another at Marlinton, and possibly one near Cass, midway between these points. In addition to these possibilities still other streams may have discharged westward into the Plateau.

ADDITIONAL EXAMPLES OF SUPERPOSITION

In addition to the cases of apparent superposition which have been described in the preceding paragraphs, there are a number of other instances where streams cut across the structures of the rocks. Some of the more important of these will be noted at this point.

At Petersburg, West Virginia, South Branch of the Potomac River flows across the southern end of Patterson Creek Mountain. A few miles to the southwest the same stream is flowing northward in a narrow meandering channel on the western slope of Cave Mountain. A similar situation, except for the meanders, is found in the case of Moorefield River, in the southern part of the

Petersburg, West Virginia, quadrangle, where the stream is flowing in a very narrow channel along the eastern slope of South Fork Mountain. This is especially peculiar in view of the presence, a short distance to the east, of the parallel, subsequent Sweedlin Valley unoccupied by a through-flowing stream. A third rather odd drainage position is on the Moorefield, West Virginia, quadrangle, where South Branch of Potomac River flows through The Trough, a narrow gorge, five miles in length. The last three drainage features involve parts of streams which flow northeastward, parallel to the strike, but located on resistant rock instead of on weak rock of subsequent valleys.

Baker Run, east of Moorefield, flows southeastward across the belt of hard rock forming Big Ridge and Short Mountain.

Just north of Romney, West Virginia, South Branch, leaving a soft rock lowland, makes a westward swing across Mill Creek Mountain. Several miles farther on it swings eastward across the same structure. Just west of Romney, Mill Greek has cut a sharp, transverse gorge across Mill Creek Mountain. A little farther to the south, on the Wardensville, West Virginia-Virginia, quadrangle, North River flows across Short Mountain, while Lost River has a diagonal course across several low ridges west of Wardensville.

All of the cases cited in the preceding paragraphs lie within the Potomac basin. Some of the streams involved flow directly southeastward or eastward across the rock structures, but three or four flow northeastward parallel with the strike of the resistant formation.

Further illustrations are found in the drainage basin of Shenandoah River. North Fork of the Shenandoah flows through Little North Mountain at Brocks Gap west of Broadway, Virginia; North River has cut a gap between Lookout and Narrow Back Mountains north of Staunton, Virginia; other tributaries of South Fork of the Shenandoah, such as Dry River, Briery Branch, and Buffalo Branch, have cut water gaps in the Appalachian Ridges. A good example in the James River basin is North River which has cut a gap in Little North Mountain, ten miles from Lexington, Virginia.

New River, if it has been superposed, had a northwesterly direction given to its course. Of special interest is the pair of wind gaps northwest of Blacksburg, Virginia. The gap in Brush Mountain has a present altitude of 2650 feet while the one in Sinking Creek Mountain to the northwest is 200 feet lower. They are very sharply defined features and quite obviously mark the position of an early stream which flowed by way of Newport into the present basin of Sinking Creek and thence into New River. The gaps are several hundred feet above the Harrisburg peneplane and somewhat more than that below the Schooley. This indicates that the piracy took place during the Harrisburg cycle.

It is probable that the basin now drained by North Fork of Roanoke River formerly discharged across these two mountains to the New River. Later in the Harrisburg cycle, this drainage was carried directly to the New River southwest of Blacksburg, the diversion having been effected by a stream occupying the approximate position of Tom's Creek. Soon after the beginning of post-Harrisburg time, the basin of the present North Fork of Roanoke River was stolen from New River by a tributary of the Roanoke. This piracy is described more fully in another section.

Drainage Changes

General statement

When the entire erosional history of the Newer Appalachians is considered, it is obvious that many drainage changes have occurred. There are numerous wind gaps just below the level of the Schooley peneplane which mark the positions of streams before adjustment to rock structure took place. In addition to the large number of piracies following the close of the Schooley cycle, there are others which took place during Harrisburg time. One of the clearest examples of mid-Harrisburg diversion is in the ridges north of Blacksburg, Virginia. The wind gaps in Brush

and Sinking Creek Mountains show the position of a stream which survived until the Harrisburg cycle was considerably advanced. Drainage changes that were associated with the uplift which inaugurated the post-Harrisburg cycle are illustrated by the piracy of the tributaries of New River by Roanoke River, and also by a series of changes in the area around Natural Bridge, Virginia. These cases are described in other sections of this paper.

In addition to those changes which have already occurred, there are others which are about to take place. An example of imminent piracy of the intercision type is found at Mount Crawford, Virginia, where North River and Cooks Creek have cut into the narrow divide between them until a mere strip carrying the Lee Highway remains. The drainage relations in the Mount Crawford locality are described by Watson, Cline, and Harnsberger (*67*). A similar condition is found on the Lee Highway between Edinburg and Woodstock where Narrow Passage Creek and North Fork of Shenandoah River have almost eliminated the divide between them. A few miles west of Natural Bridge, a tributary of Cedar Creek is about to tap the waters of the main stem of Cedar Creek on top of the Short Hills synclinal mountain in the vicinity of Spring Gap.

Many of the streams flow in subsequent valleys. Frequently two subsequent streams discharge in opposite directions from a low transverse divide. As a rule, the divides are fairly stable with little or no evidence to indicate that one stream is gaining at the expense of the other. In regions where piracy has occurred as recent as the early part of the post-Harrisburg cycle, the competing streams have not yet reached equilibrium and consequently the divides are still shifting. This is true, for instance, in the upper Roanoke River basin.

STREAM TYPES

Of all the genetic stream types, the subsequent is much the most common in the areas of folded rocks. Lateral consequent streams are represented by the outlets from an unroofed anticline like that of Warm Springs valley. Very typical obsequent streams flow from the rimming mountains into the axial subsequent streams

which unite to form the lateral consequents. Longitudinal consequents, in a region as old as this, are difficult to demonstrate. If the Johnsonian theory of regional superposition can be properly applied to this area, then the superposed streams described in a previous section are consequents. Resequent streams can be traced on the inner cores of unroofed anticlines.

DRAINAGE PATTERN

The trellis drainage pattern is widely developed in all parts of the region. It is most perfect where the rock belts are narrow and strongly contrasted in resistance, as in the Monterey, Virginia-West Virginia, quadrangle. Where the belts of resistant rocks are relatively broad, the headward tributaries are apt to be insequent in origin, and the local pattern dendritic. Allegheny Mountain in the northwestern part of the Monterey quadrangle represents this condition.

STRUCTURAL TYPES OF RIDGES AND VALLEYS

All of the common structural types of ridges and valleys are abundantly represented between the Potomac and New Rivers. Monoclinal ridges are most numerous, but anticlinal and synclinal ridges are typically represented in various localities. The Monterey region in the western part of Virginia is the best for a study, in a short traverse, of the six common structural types of ridges and valleys. From Jack Mountain to Allegheny Mountain, the highway passing through Monterey crosses in an airline distance of fifteen miles, an anticlinal ridge and an anticlinal valley, a synclinal ridge and a synclinal valley, two monoclinal ridges and a monoclinal valley. There are three magnificent anticlinal valleys in this region, Crabbottom valley in the Back Creek Mountain arch, Big Valley in which Bolar is located, and Warm Springs valley. Shenandoah and Allegheny Mountains are synclinal, while Bullpasture Mountain and the northern end of Jack Mountain are anticlinal. Monterey Mountain is one of the best examples of an even-crested monoclinal ridge.

One of the most unique relief features of the area is Massanutten Mountain. It is fifty miles in length, and extends from

Strasburg on the north to Harrisonburg on the south through the heart of the Valley of Virginia. It separates the two forks of the Shenandoah River which unite at its northern end. It is a complex synclinal fold and has a typical abrupt nose at each end. These "peaks" are landmarks in the Valley, the southern one, known as The Peak, being one of the most conspicuous points in the region around Harrisonburg, Virginia.

THE UPPER ROANOKE RIVER

The Roanoke River is unusual among southeastward-flowing streams in the Appalachians in that it drains only a small area west of the Blue Ridge and was never superposed across the Appalachian Ridges. It is also unique in the fact that it has captured since the close of the Harrisburg cycle an area of approximately two hundred square miles that was formerly drained by New River.

Roanoke River is formed by the junction of North and South Forks at La Fayette, twenty miles west of Roanoke, Virginia. North Fork has its source in a narrow valley in the Appalachian Ridges between Brush and Paris Mountains in the northwestern corner of Roanoke County. It flows southwest and then south along a subsequent valley, underlain by limestone and shale, to the vicinity of Trinity Crossroads where it turns sharply to the northeast. It continues in this direction until it unites with South Fork.

South Fork rises between Bent and Poor Mountains in the area of crystalline rocks to the south. Its upper tributaries, Bottom Creek and Lick Fork, flow southwestward and are joined by Elliott Creek, and other streams from the west, before turning to the north to unite with North Fork. From La Fayette to the city of Roanoke, Roanoke River is a normal subsequent stream. Tinker and Glade Creeks are important tributaries from the north and northeast at Roanoke, while Back Creek enters the master stream some five miles farther downstream. The Blue Ridge is broken down at this point and consequently the stream has no true water gap through it. The study of the drainage history of this region is facilitated by referring to the Bedford,

Virginia, and the Christiansburg, Virginia-West Virginia, topographic maps, as well as to the recently published fifteen minute maps of the Roanoke and Salem quadrangles.

The most distinctive feature of the Roanoke basin today is the steep escarpment leading down from the higher New River level to the lower Roanoke level. So pronounced is this slope that the average motorist in passing from La Fayette to Christiansburg thinks he has ascended a mountain. Actually he has just passed from the Harrisburg erosion surface as it is developed around Salem and La Fayette up to the surface developed in the same cycle by the tributaries of New River in the Christiansburg area. Differences in elevation between Harrisburg local peneplanes in nearby areas in the Older Appalachians have already been described (*71*). The occurrence of two Harrisburg levels in the Appalachian Valley, separated by an escarpment of at least 600 feet, is known to the writer only in the Roanoke-Christiansburg area.

During the Harrisburg cycle the Roanoke River probably did not drain much of the area now occupied by North and South Forks. The eastern end of Pedlar Hills, which separate the present Forks, marked the approximate position of the divide. A few traces of the Harrisburg surface may be seen between La Fayette and Shawsville on the South Fork. Above this point the writer could not identify it with certainty. Flatwoods Branch and Bradshaw Creek may have drained into the Roanoke during the Harrisburg cycle, as indicated by their broad valley floors. The presence in these valleys of a surface between 1500 and 1600 feet above sea level argues strongly for their discharge into the Roanoke basin in that cycle. Regardless of the exact location of the Harrisburg divide, we can be fairly sure that the main part of the area of the present North and South Forks drained formerly to the west into New River.

There seems to be no evidence to indicate any great shifting of the divide between Mason Creek, which enters the Roanoke near Salem, and any of its neighbors. Judging by the spacing of the contours, the constriction of the valley at Cloverdale, and the asymmetrical position of the Tinker Creek-Catawba Creek divide,

Tinker Creek may have pushed its divide northward in post-Harrisburg time. In a limestone area, such as this, it is difficult to demonstrate the shifting of a divide, but the above evidence indicates that a northward shifting between Tinker Creek and Catawba Creek may have taken place.

There seems to be no satisfactory explanation for the present drainage arrangement in the upper Roanoke River system except on the basis of stream piracy. The basin brings out a rather unusual series of Harrisburg surfaces. Starting at Roanoke, with an elevation of approximately 1060 feet, the surface rises within a short distance from the city in all directions, except downstream, to altitudes between 1100 and 1150 feet. It is beautifully preserved around Cave Spring south of Salem at an elevation of about 1100 feet. From this point to Poges Mill it rises to 1300 or 1400 feet. Proceeding up the Roanoke, the peneplane attains a height of 1500 feet in the vicinity of La Fayette.

Stose (*56*) in his treatment of the Valley of Virginia describes the features along the divide between the New and Roanoke Rivers in the following terms: "At the forks of Roanoke River the valley begins to broaden but is obstructed by the Pedlar Hills, a tract of country over 2000 feet in altitude, through which the main streams flow in narrow gorges 700 to 800 feet deep, giving rise to scenery much more rugged than is common in the Valley of Virginia. The even tops of the Pedlar Hills, which represent the floor of this part of the valley, are 2000 to 2200 feet in altitude and are distinctly not a part of the low plain of the Salem Valley about Roanoke, although the area is drained by branches of Roanoke River, but are part of the next valley to the southwest, whose floor has about the altitude of the tops of the Pedlar Hills and is almost continuous with them."

As one surmounts the east-facing escarpment, he finds an open, westward-sloping basin. The divide, however, is not along the rim of the escarpment but some distance to the west, and is therefore not conspicuous. The eastern part of this upland surface has been grandly dissected by tributaries of Roanoke River which have gnawed back into it and captured some of the streams which flowed to the west. A view of the dissected upland in the crystal-

lines is shown in Plate XVIII. This upland level is approximately 2200 feet in elevation on the limestone floor of the Appalachian Valley, but it rises up the tributaries of South Fork to well above 2500 feet. Near the heads of the streams the Harrisburg surface appears to be approximately 2700 to 2800 feet above sea level (*Plate XVIII*). The ascent is rather steep in the upper parts, and it must be understood that the Harrisburg in that situation is not a regional peneplane, but rather a local peneplane, and in some cases just a mature valley.

The Harrisburg surface on North Fork does not rise appreciably higher than the general level of the Blacksburg-Christiansburg area. Before the piracy occurred, the main upper stem of North Fork presumably flowed southwest across the present divide in the vicinity of Blacksburg.

Stose (*56*), using elevation as the prime criterion in correlating erosion surfaces, finds remnants of a peneplane in the Salem valley, near Roanoke, which articulate with other features at the same elevation in the Fincastle valley and concludes that the James has been shorn of an important tributary by the Roanoke. This tributary developed the higher level in the present Roanoke valley. Thus he says, "The peneplain that forms the floor of the Fincastle Valley, remnants of which occur also in the Salem Valley and in the intermontane valleys to the north, is 1,500 feet in altitude. This plain was formed by the erosion of the James River system, and its lower altitude is due to its being nearer the ocean by that direct course. The floor of the Dublin Valley, including Cripple Creek and Rye Valleys at its upper end, is 2,200 to 2,700 feet in altitude."

Some of the high-lying valleys drained by the headwaters of the James and the Potomac have their present floors at elevations between 2500 and 3000 feet. Consequently, according to Stose, they must have formerly flowed westward into New River. He describes these relations in the following terms: "Those valleys which are now drained chiefly by the headwaters of the James, the northern parts of which, however, are drained northward by the headwaters of the Potomac, have floors between 2,500 and 3,000 feet in altitude, and it is believed that at the time they were

formed they were tributary to New River whose floor was at this level. Their drainage has since been diverted by stream capture to the more direct course to the ocean by James River, which had a much steeper gradient."

Evidence of Capture

Perhaps the most striking evidence of drainage change is the notably barbed character of North and South Forks of Roanoke River. This is brought out in Figure 1. The upper courses of these streams are perfectly in accordance with expectable drainage directions for tributaries of New River, but they are abnormal as tributaries of the Roanoke.

The erosion surface produced in Harrisburg time by New River slopes toward the master stream. The upper tributaries of the Roanoke now drain an area which was apparently peneplaned in Harrisburg time by a stream or streams which flowed to the west, that is, toward New River. When it is demonstrated that a peneplaned surface of Harrisburg age slopes in a given direction, the direction of slope being determined largely by the direction of flow of the streams which carved it, we can infer that a stream which at present is flowing opposite to this slope did not exist, or was not flowing in that direction in the Harrisburg cycle.

The topographic evidence along the present divide between the New and the Roanoke supports the theory of capture. It is especially convincing along the South Fork. A passable road leads from Christiansburg to Copper Hill by way of Huffville, Terrys Fork, and Locust Grove, as indicated on the Christiansburg, Virginia-West Virginia, quadrangle. To the northeast of this road, the topography is quite rugged due to deep dissection by the vigorous tributaries of South Fork, as may be seen in Plate XVIII. At the same time, the level of the Harrisburg peneplane is easily detected, because dissection has not gone far enough to destroy the interstream areas. The depth of dissection is over 500 feet, and the relief is as great as it is around Saluda, North Carolina, where the Green and Pacolet Rivers have gnawed back into the Blue Ridge scarp and dissected the upper part of the Harrisburg basin of the French Broad River. It is apparently

quite a comparable situation, except that in the case of Roanoke River the stream has pushed in by way of the Appalachian Valley rather than by the Piedmont as in the North Carolina locality.

To the south of the Christiansburg-Copper Hill road, the valleys are more open, the slopes much gentler, and the drainage leads into Little River, a tributary of the New. The contrast in degree of dissection on the two sides of the divide is quite striking (*Plates XIX and XX*). Elliott Creek, flowing from the southwest, opposite in direction to the original drainage, has dissected the New River level to a depth of more than 500 feet where it joins Bottom Creek.

Along this modern divide between New River and South Fork of Roanoke River there do not seem to be any strips of the Schooley surface such as have been pointed out in the Hillsville area to the southwest (*71*). In the latter district the major divides are characterized by strips of upland which have a fair accordancy. These have been tentatively interpreted as Schooley. It is interesting to note that along the present divide between New River and South Fork of Roanoke River there are no such remnants, and the divide was apparently well peneplaned in the Harrisburg cycle. Pilot Mountain is certainly a monadnock above the Harrisburg level and it may be a remnant of the Schooley peneplane. As one passes from Christiansburg to Floyd, he is impressed with the fact that the Harrisburg surface of the Valley rises gradually to the Harrisburg level of the Older Appalachians. The accordance of these two parts of the Harrisburg record is perhaps even more striking here than that in the Hillsville-Fort Chiswell profile.

Another evidence of capture is seen in the youthful characteristics of North and South Forks and their tributaries. The valleys are gorges and there are local falls and miniature hanging valleys. It is only in the subsequent parts of these valleys that the stage of early maturity is reached. From Bennetts Mill south toward Trinity Crossroads, North Fork flows in a fairly open valley on limestone. The tributaries even in this part of its valley have steep gradients and markedly youthful characteristics. South Fork, particularly above Alleghany Spring, has an

especially narrow valley, and its tributaries are even more youthful. The dissection of this part of the crystalline area by South Fork and its tributaries is comparable to the dissection of the Blue Ridge scarp a few miles to the east.

Pedlar Hills, a strip of upland between North and South Forks, doubtless belonged formerly to the New River drainage basin. Stose (*56*) so interpreted it. The "Hills" at the present time are very intricately dissected, much more so than the contours of the Christiansburg quadrangle would indicate. The narrow-crested divides and sharp hilltops are separated by precipitous slopes leading down to deep, youthful valleys. In spite of its great dissection, there still remains a considerable degree of accordancy in the skyline.

Assuming no change in the position of the divide between the New and Roanoke Rivers since the Harrisburg cycle, we should expect to find the present head of Roanoke River but slightly below its position at the close of the Harrisburg cycle. In almost all of the Harrisburg areas, the depth of intrenchment in the present cycle decreases upstream until at the headwaters the present stream level is nearly the same as that in the Harrisburg cycle. Let us apply this principle to the Roanoke basin. An instructive viewpoint for such an observation is on prominent hilltops near U. S. Highway No. 11 between Glenvar and Big Hill Church southwest of Salem, Virginia. From this point, one can look eastward and see the Harrisburg surface of Roanoke River at an elevation of approximately 1140 feet near Salem rising to 1200 feet near the base of the mountains on either side. Between Glenvar and Big Hill Church, the erosion surface is probably 1350 feet in elevation, while at the junction of North and South Forks, three miles to the southwest, it is approximately 1500 feet. The imposing Pedlar Hills and the mountains to the north and south form a very impressive wall, and it is impossible to trace the Harrisburg surface in the narrow valleys and ravines of this mountainous upland.

On the basis of piracy, however, the above relations are easily explained. The Harrisburg surface of the Salem region rises gradually upstream to Glenvar where its gradient steepens rapidly to the region of the former head of the stream slightly west and

southwest of La Fayette. This surface does not rise high enough to articulate with the New River level on the Pedlar Hills and hence the two were not produced by the same stream. There is a distinct discordance in elevation, a break between two basins drained by streams which flowed in opposite directions. The increased volume, following capture, has permitted the deep intrenchment of Roanoke River above and below La Fayette. This intrenchment amounts to approximately 275 feet, which contrasts with 140 feet at Salem. If piracy had not occurred, the depth of dissection would normally be greater at Salem than at La Fayette.

The drainage history in the lowland now drained by Catawba Creek, which flows northeast to the James, and North Fork of Roanoke River, is not entirely clear. From various points near Shiloh Church, Salem quadrangle, one can see the southwest-sloping Harrisburg surface fusing in the distance with the New River surface in the vicinity of Blacksburg. This surface seems to be traceable to the northeast of Shiloh Church perhaps as far as Catawba, and it certainly occurs east of the present divide between the heads of Catawba Creek and North Fork. If this is true, Catawba Creek has shared with Roanoke River in the piracy of this part of the New River basin. Trout Creek, with its source in the area west of Shiloh Church, has cut off a considerable slice of New River territory which now drains northward to Craig Creek, an important tributary of the James. The last-named stream, through the headward erosion of Catawba and Craig Creeks, has extended its own basin into what was formerly New River territory.

The col marking the divide between Catawba Creek and North Fork is a beautiful valley, which, in its transverse profile, is quite unlike the normal divide between the heads of two subsequent streams. Its characteristics are clearly represented on the recently published Salem topographic map. It appears that North Fork is gaining ground on Catawba Creek, the earlier pirate. Regardless of the details of the recent drainage history in the region, it is interesting to note that both the Roanoke and the James have, since the close of the Harrisburg cycle, gnawed back into the high-lying New River basin.

The Cause of the Piracy

Campbell (*12*) has proposed warping as an important factor in the determination of the New-Roanoke divide, as well as in the development of the Blue Ridge scarp. It is now known that Harrisburg surfaces normally rise upstream. The elevations in adjacent drainage basins may vary appreciably. If one examines the Christiansburg quadrangle, he will find an interesting diversity of levels. The Harrisburg surface in Floyd County in the southern part of the quadrangle reaches an elevation of about 2800 feet. In the Sinking Creek valley in the northwestern part of the map, a fairly well defined Harrisburg remnant appears approximately 2550 feet above sea level. In the Christiansburg-Blacksburg area it is broadly developed at 2200 feet. In the Craig Creek shale valley, the surface is well preserved at an elevation of about 1500 feet near the northern margin of the map. Finally, the peneplane developed by Roanoke River around Roanoke is only 1060 feet above tide.

The factors which determine the elevation of the Harrisburg erosion surface include distance to the sea, stream volume, presence or absence of resistant rocks across the stream, and rock resistance, including contrasts between soluble limestone and less soluble shale. The strong contrast in stream length, or distance to the sea, is the most important factor in causing a difference of 600 to 700 feet between the Harrisburg erosion levels of the New and Roanoke Rivers. The length of the former is approximately six times that of the latter. The volume of the New is greater than that of the Roanoke, which tends to reduce the advantage of shorter distance to the sea enjoyed by the Roanoke. The resistant quartzite which the New flows across at Narrows, Virginia, tended to hold up the Harrisburg surface to the south.

If these diversities in elevation existed at the close of the Harrisburg cycle, as they may have, it would be only reasonable to expect that with the uplift which terminated the cycle there would be stream captures in certain favorable situations. The soft rock belt, extending across the divide between the New and Roanoke River basins, provided such a condition. With the rejuvenation of the Roanoke, its headward tributaries gnawed

rapidly into the New River basin and in time accomplished the series of changes which gives us the present drainage arrangement. While warping may have played a minor rôle, it seems unnecessary to invoke a factor outside of the normal erosive processes which are operating in the region.

The head of the vigorous Elliott Creek is now less than six miles from the nearest bend of New River. The New at this point is flowing at an elevation of approximately 1750 feet, while the Roanoke at La Fayette, twenty miles to the east, has its bed just 1225 feet above sea level. Under such circumstances the future course of events in respect to this divide is clear. Assuming the continuance of normal erosive processes, Elliott Creek will obviously cut headward until it finally captures the New. The piracy can hardly be said to be imminent, but it is certainly not remote.

Special Features in Limestone

A large part of the Valley of Virginia, and a considerable number of areas in the Appalachian Ridges, are underlain by limestone, some of which is very pure and hence highly soluble. There are many examples of differential chemical weathering in the abundant rock outcrops which occur in parts of the limestone area. Some extremely smooth surfaces are exhibited. Fine grained rocks of uniform composition, such as the Athens formation in the neighborhood of Harrisonburg, weather very uniformly. Resistant substances such as fossils and chert nodules stand out from the rock surfaces. Small solution pits may alternate with these resistant features producing a rough surface. The depth of residual soil varies greatly in limestone regions due to variations in the spacing of joints, variable degrees of solubility, differences in the attitude of the surface, and other causes.

Abundant joints and well-defined bedding planes exert a great control in guiding the agencies of weathering and even the processes of erosion. This accounts for spires, columns, and small pinnacles which project from the bed rock. These are especially common in valley walls. Natural Chimneys, now called Cyclopean Towers, fifteen miles north of Staunton, Virginia, are a striking illustration.

LIMESTONE SINKS

Sinks in limestone are abundant in many parts of the region. They are so common that it is not necessary to list localities. In some areas all of the surface water passes through sink holes to nearby streams. They occur in considerable number in the Berryville and Natural Bridge regions, in Virginia, and very abundantly in the Lewisburg Lowland, in West Virginia. There is scarcely a limestone locality which does not have at least a few typical sinks. They vary in size from a few feet in diameter up to basins several miles in length. Some contain water, but most of them are dry.

LOST RIVERS

Surface streams which sink underground and reappear farther down the valley are likewise characteristic features of limestone localities. Lost River near Wardensville, West Virginia, flows about two miles underground. Sinking Creek disappears near the eastern margin of the Dublin, Virginia-West Virginia, quadrangle. Hills Creek in the eastern part of the Lobelia, West Virginia, quadrangle, disappears in a large sink but does not rise again and hence loses its identity. There are, in fact, quite a few streams of this type whose waters join the groundwater or emerge in some lower valley.

Although they are not peculiar to limestone regions, it is perhaps in order to refer to the thermal springs in western Virginia. They have been recently described by Reeves (*48*), who thinks their temperature is due to passage through rock formations at great depth. The structural conditions, as Reeves points out, favor this process by permitting the water to enter the ground on a high anticline, pass through the heated rocks in the deep floor of a neighboring syncline, and then emerge from the core of a breached anticline.

Normal springs are abundant in the region and many of them carry considerable quantities of lime carbonate in solution. The precipitation of calcareous tufa or marl from such waters is common, and deposits of this substance are found in many of the

streams which follow dip courses, as well as in some of the strike valleys of the region.

CAVERNS

Although they have no surface expression, it is well to bear in mind the large number of caverns that have been developed in the limestones of the Valley of Virginia through the agency of underground water. A beautifully illustrated volume on the Caverns of Virginia has recently been prepared by McGill (*43*) and published by the Virginia Geological Survey.

THE NATURAL BRIDGE OF VIRGINIA

General Statement

The Natural Bridge of Virginia, a most unique and impressive scenic feature, is located in the Valley of Virginia, fourteen miles southwest of Lexington. It spans a picturesque canyon and carries U. S. Highway No. 11, the arterial route through the Appalachian Valley.

It is only to be expected that such an attractive object as Natural Bridge should find its place in the notes and journals of early travelers in this region. Its legendary renown dates back to Indian days. According to Reeds (*47*), the earliest reference to the Bridge is by Burnaby, who spoke of it as "A natural arch or bridge joining two high mountains, with a considerable river underneath." A charming story from the early history of the region runs as follows (*47*): "The Monacan Indians handed down through generations the history how their tribe was wasted and decimated by long wars with the Shawnees and Powhattans. Worn by famine and despair, they were flying closely pursued through strange forests when they came upon a great chasm of incredible depth, a hundred feet from brink to brink, extending for miles to the eastward and to the westward. In the anguish of defeat, they prostrated themselves, and called upon the Great Spirit to spare his children. And when they arose and looked, behold a bridge spanned the abyss! The women and children were sent forth to try its strength. Seeing that it bore them, the prudent braves followed; and their pursuers coming up, they held the bridge as it were Thermopylae, and put many times their own number to death or flight. Therefore, the Monacans called it the Bridge of God, and worshipped it."

The visitor to the Bridge is shown the initials "G. W." which are carved on the southeast wall more than twenty feet above Cedar Creek. These are supposed to have been chiseled by George Washington himself. A few years ago some workmen, while excavating along the side of the canyon below the Bridge, discovered a huge boulder which bears the marks of a surveyor. That Washington visited the Bridge is well within the bounds of possibility, although historical confirmation is lacking.

On July 5, 1774, the tract of land comprising 157 acres on which the Bridge is situated was transferred by King George III of England to Thomas Jefferson. The consideration was twenty shillings. Mr. Jefferson took great pride in this property and once referred to the Bridge as "the most sublime of Nature's work." He even made the first known map of it the year after his first inauguration as President of the United States. During the period of its ownership by Jefferson, many distinguished persons were entertained in a cabin erected by Jefferson which was presided over by Patrick Henry and his wife.

Reeds (*47*) refers to the prominent place given to this feature by De Chastellux in his volume entitled, "The Travels of Marquis de Chastellux in North America in 1780–82." This description was widely circulated in Europe and through it the Bridge became well known abroad.

The origin of the Bridge has received attention from Jefferson's time to the present. Five of these contributions will be noted, although there are just two published theories which deserve serious consideration.

Review of Previous Work

Jefferson in his "Notes on the State of Virginia" speaking of the Bridge says, "It is on the ascent of a hill which seems to have been cloven through its length by some great convulsion." Gilmer (*33*), in commenting upon this explanation, makes the following pertinent statement: "Mr. Jefferson's hypothesis rested entirely upon the supposition, that some sudden and violent convulsion of nature, tore away one part of the hill from the other, and left the bridge remaining over the chasm."

Accompanied by Jefferson, Francis W. Gilmer visited Natural Bridge in 1815. In his discussion (*33*) of the origin of the Bridge, he opposed the cataclysmic idea which Mr. Jefferson had previously stated. The essence of Gilmer's theory is contained in the following lines: "It is probable, then, that the water of Cedar Creek originally found a subterranean passage beneath the arch of the present bridge, then only the continuation of the transverse ridge of hills. The stream has gradually widened, and deepened

this ravine to its present situation. Fragments of its sides also yielding to the expansion of heat and cold, tumbled down even above the height of the water. . . . . The stone and earth composing the arch of the bridge, remained there and nowhere else; because, the hill being of rock, the depth of rock was greatest above the surface of the water where the hill was highest, and this part being very thick, and the strata horizontal, the arch was strong enough to rest on such a base." It is remarkable that at this early date Gilmer recognized the fact that the surface features of the earth are produced not by sudden cataclysms, but through the long continued operation of orderly processes. He expresses this idea in the following words: "Instead of its being the effect of a sudden convulsion, or an extraordinary deviation from the ordinary laws of nature, it will be found to have been produced by the very slow operation of causes which have always and must ever continue to act in the same manner."

Both Jefferson and Gilmer refer to the feeling of fear aroused in those who viewed the Bridge from above. One can well imagine, as he stands behind the protecting rail on Pulpit Rock and looks down into the gorge beneath him, the state of mind of those early observers. Jefferson says, "If the view from the top be painful and intolerable, that from below is delightful in an equal extreme." Gilmer (*33*) adds, "The curiosity of most persons, however, is overcome by fear, before they reach the margin of the precipice; they either abandon the enterprise, or timidly accomplish it by resting on a tree or rock, while they peep into the chasm which yawns beneath."

The theory presented by Walcott (*64*) in 1893 was the next to receive serious consideration from geologists. It was widely accepted and it appears in some textbooks. Diagrams were made to show how the water of Cedar Creek entered the bed of the stream above the present site of the Bridge and emerged at the base of a supposed fall located below the Bridge. Walcott summarized the theory as follows: "Cedar Creek was engaged for a considerable period in excavating the gorge from the James River to a point not far below the present site of the bridge, where a fall appears to have existed, the summit of which was not far, if at all,

below the present level of the top of the bridge. About this time the water found a subterranean passage in the limestone further up the stream than the present site of the bridge, and through this it flowed and discharged beneath the brink of the falls. The passage gradually enlarged until all the waters of the creek passed through it and the bridge began its existence. What the length of the subterranean passage was is a matter of conjecture; it may have been one hundred or several hundred feet. All of its roof has disappeared except the narrow span of the bridge, and the abutting walls have been worn back by erosion until the gorge or canyon is much wider than at the bridge."

Chester A. Reeds (*47*), in 1927, made a study of Natural Bridge under the auspices of the Natural Bridge of Virginia, Inc., and prepared an attractively illustrated guidebook primarily for the use of tourists. It contains an elaborate description of the Bridge and many other local features of interest and beauty, such as Cascades Creek, Lost River, and Lace Falls. The author also gives a clear account of the geologic and physiographic history of the region and especially that of the Bridge itself. The local history since Indian days is carefully reviewed as is also the bibliography of Natural Bridge.

Malott and Shrock (*44*) examined the gorge and the topographic features of the surrounding area, and presented their results in 1930 in the American Journal of Science, under the caption, "Origin and Development of Natural Bridge, Virginia." They confirmed, and elaborated at length the Gilmer theory. Under their treatment, the theory becomes attractive and reasonable. They believe that the Bridge and the gorge are due to a subterranean cut-off of a meander loop of Cedar Creek. Thus they say, "It appears that the waters of Cedar Creek were diverted through a subsurface passage beneath a rather open meander spur." These authors have gone exhaustively into the literature of Natural Bridge, and the reader is referred to this excellent essay for a thorough treatment of the problem of origin and for a complete list of references.

The Natural Bridge

Natural Bridge is a natural arch or slab of limestone which spans the gorge of Cedar Creek. (*Plate XXI.*) The length is approximately 90 feet, the width varies from 50 to 150 feet, and the thickness averages 50 feet. Reeds estimated the weight of the Bridge as 36,000 tons. The height of the upper surface of the Bridge above the water of Cedar Creek, is given by the same author as 195.5 feet.

The Natural Bridge Region

Natural Bridge is located in a narrow section of the Valley of Virginia where the easternmost members of the Appalachian Ridges to the west are not more than seven or eight miles from the Blue Ridge. The region under consideration extends from Lexington southwestward a distance of approximately twenty-five miles to Buchanan. At the latter point, the Appalachian Valley is barely two miles wide, while at Lexington its width is about fifteen miles. In the vicinity of Natural Bridge, halfway between Buchanan and Lexington, the distance is approximately eight miles from Short Hills on the west to the Blue Ridge on the east. These two mountains form the conspicuous boundaries of the Valley in the vicinity of Natural Bridge. James River, the master stream, flows from Buchanan northeastward by Natural Bridge Station to Glasgow, where it breaks through the Blue Ridge. North River, rising in the mountains to the west, flows eastward by Lexington and is joined by South River near the base of the Blue Ridge, before continuing southwestward to unite with the James east of Glasgow. Buffalo Creek, another important tributary from the west, crosses the Valley between Lexington and Natural Bridge and enters North River.

Cedar Creek, the stream which flows under Natural Bridge, has its source near the southern end of the synclinal Short Hills mountain, and flows northeastward along the axis of this fold until it discharges down its northeastern end. Once off the mountain, it turns southwestward, then southeastward across the rock structure, and passes on through its gorge under the Bridge until

it finally empties into James River at Gilmore Mills (*Plates XXII* and *XXIII*).

Just west of Glasgow and Balcony Falls, stands Sallings Mountain. It is composed of Cambrian quartzite, and it is almost cut into two parts by a deep wind gap, the floor of which has approximately the same elevation as the Harrisburg surface to the west.

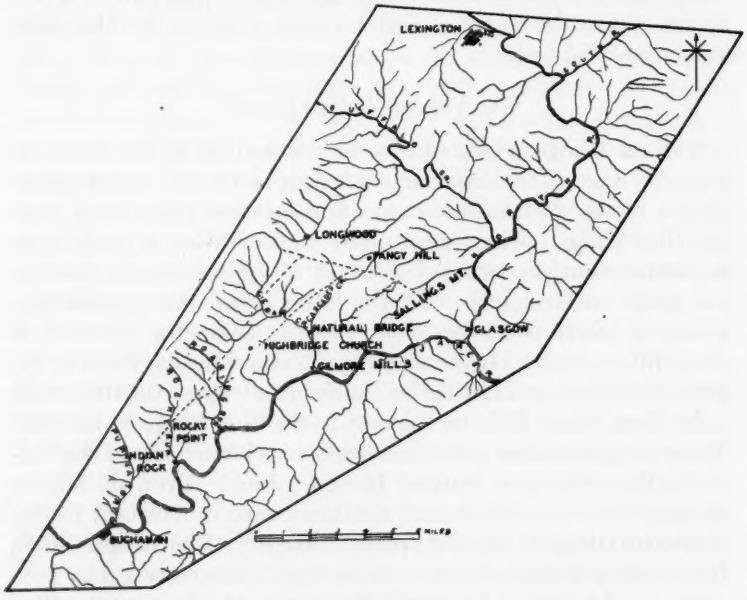

FIG. 2. DRAINAGE MAP OF THE NATURAL BRIDGE REGION

Broken lines indicate the position of streams in the Harrisburg cycle. (From the United States Geological Survey topographic maps.)

The features of the region between Lexington and Buchanan are shown on the Lexington and Rockbridge quadrangles of the U. S. Geological Survey. For the local area of the Bridge, the reader is referred to the Natural Bridge Special topographic map. The entire course of Cedar Creek and most of the critical points in the topography of the region are portrayed on this map. Sallings Mountain, however, appears near the western margin of

the Lexington quadrangle. The drainage lines are shown in Figure 2.

Problem of Two Harrisburg Surfaces

The origin of Natural Bridge and the gorge of Cedar Creek should be sought in the drainage history of the region. For this purpose an area extending from Lexington to Buchanan and involving a number of streams has been studied in the field and laboratory. Any explanation that is proposed for the local features in the vicinity of Natural Bridge must fit into the history of this larger area.

In order to understand the present features of the region, it is necessary to go back as far as the Harrisburg cycle. It is obvious that we must investigate the positions of streams of that time in order to determine what modifications, if any, have resulted in the present system.

After a careful study of the field and map evidence, it appears that we are dealing here with two Harrisburg surfaces which are separated by an escarpment of approximately 250 feet in the vicinity of Natural Bridge. First, there is the erosion surface of the James River which at Buchanan has an altitude of about 1050 feet. It descends gradually downstream to an elevation of 1000 feet at Natural Bridge Station and Glasgow. The other Harrisburg surface was developed by subsequent tributary streams which occupied positions northwest of the present Natural Bridge. One of these had its source near Highbridge Church and flowed southwestward in the general direction of the Plank Road. Another stream carried the drainage from Highbridge Church northeastward and eastward through Sallings Mountain to North River. This was a part of the ancestral Cedar Creek drainage system. The Harrisburg surface of each of these tributary streams rises upstream to a maximum elevation of approximately 1400 feet on the divide between them. From this point there is a definite downstream slope to the Harrisburg surface of the James River at Buchanan and a corresponding slope toward the wind gap in Sallings Mountain. The escarpment between the two surfaces is traced on the map and in the field from a point just

north of Buchanan to Sallings Mountain. It is highest near Natural Bridge, and Cedar Creek discharges across it near the point of its maximum elevation.

Evidence in Support of Two Harrisburg Surfaces

In another section of this paper it has been shown that Harrisburg surfaces rise upstream along the master stream as well as along its tributaries. So far as the writer is aware, this is almost universally true in the Southern Appalachians except where piracy has occurred. Since James River flows northeastward from Buchanan to Natural Bridge Station the Harrisburg surface of this stream should slope down in that direction. It should be remembered also that in this part of its course the James is a subsequent stream, while just below this stretch it is cutting on the resistant rocks of the Blue Ridge. Its subsequent character combined with a downstream barrier would normally result in a relatively slight upstream rise of the Harrisburg surface in this part of its course.

Turning to the field evidence, we find the Harrisburg surface in the Buchanan area at the present time approximately 1050 feet above tide. As in other areas, the accurate determination of the present altitude of the Harrisburg is extremely difficult. It is particularly difficult in the area between Buchanan and Natural Bridge Station because of the extreme narrowness of the valley of James River in the Harrisburg cycle. As will be shown later, the tributaries of the James from the west were extremely short and arose against the escarpment separating the lower James River basin from the higher basin of the tributary whose course followed the present Plank Road. The present meander belt between Buchanan and Rockypoint represents the approximate width of the valley of the James during the Harrisburg cycle. This, of course, does not take into account the basins of tributaries which come from the Blue Ridge to the east. The elevations of the intermeander spurs between Buchanan and Rockypoint are between 1000 and 1050 feet. If these spurs preserve approximately the flood plain level of Harrisburg time, it is to be expected that the valley walls would rise at least 25 to 50 feet higher. The

point of striking interest here, however, is the fact that this intermeander level so splendidly preserved on the flat spurs northeast of Buchanan is so nearly the elevation of the Harrisburg peneplane southwest of Buchanan some distance away from the stream; also, the further fact that this same surface can be traced without interruption downstream to and beyond Natural Bridge Station. It is slightly higher back from the stream than it is on the valley walls but its apparent continuity is noteworthy. As nearly as the writer can estimate, the elevation of this surface is approximately 1050 feet at Buchanan and 1000 feet at Natural Bridge Station. There is not sufficient field evidence on which to base an estimate of its elevation near Glasgow, and hence we shall use the figure of 1000 feet for the general region of Natural Bridge Station and Glasgow. In view of its continuity and its slight downstream slope from Buchanan to Natural Bridge, it seems to the writer that its restoration in this area is a matter of reasonable certainty. Furthermore, the broad, intrenched meanders are quite similar to features in numerous other Harrisburg lowlands in the Southern Appalachians.

An alternative to the above interpretation is the possibility of the surface along the James River being the remnant of a lower and younger peneplane, which was not developed in the upland back from the stream. The writer has considered this idea but is not inclined to it. Among the arguments against its acceptance, one could mention the fact that the Harrisburg surfaces in the tributary valleys seem to slope down to and merge with the Harrisburg surface of the James River valley where the streams empty into the James.

A second line of evidence in support of the idea of two Harrisburg erosion surfaces consists in the normal upstream rise of the Harrisburg surface along the tributary valleys west of Natural Bridge. From a point about one mile north of Buchanan, one can look to the north and see the upstream rise of the basin along the Plank Road. The ascent in this basin is much steeper than along the James. This is normal for tributary streams. Turning in the other direction, one looks to the south to see the lower James River surface.

According to the present interpretation, Rocky Run and Roaring Run, with their tributaries, occupy territory which drained formerly toward the southwest through a stream which had approximately the present position of the Plank Road. The Harrisburg surface rises along this basin to a point a short distance beyond the Rockbridge-Botetourte County line. At Rockypoint and Indianrock the westward swinging meanders of James River are cutting into the eastern slope of the escarpment separating the upper and lower Harrisburg surfaces.

From the Harrisburg divide, a short distance north of the county line, the drainage flowed northeastward to join Cedar Creek, which formerly passed from the Short Hills across the low col just east of the Plank Road. By some route, unknown at present, this stream flowed eastward across the Valley and through a gap in Sallings Mountain. The Harrisburg surface, with an elevation of approximately 1400 feet at the divide, slopes southwestward to 1050 feet at Buchanan. In the opposite direction, that is, toward the northeast and east, it descends along the former course of Cedar Creek across Sallings Mountain to merge with the South River surface at an elevation of approximately 1000 feet.

The above features of Harrisburg erosion are entirely in accordance with stream directions as just stated, but not with the present direction of flow and position of Cedar Creek.

A third feature in support of the theory of two Harrisburg erosion surfaces is the escarpment which borders James River on the west. At Buchanan the Harrisburg basin of the subsequent tributary fused with the Harrisburg basin of the James River. About a mile north of the town the erosion surface of the tributary stream is rising to the north while the level of the James is declining toward the northeast. Consequently there is an escarpment between them. The farther from Buchanan, the greater the disparity between the two basins becomes, until the former transverse divide near Highbridge Church is reached. At this point the contrast in elevation is greatest, the higher basin being more than 1300 feet above the sea, and the lower slightly more than 1000 feet. From this point toward the northeast the

escarpment gradually becomes lower until it intersects the western slope of Sallings Mountain. It is seen at a number of points between Buchanan and Natural Bridge Station, as shown in Plates XXIV and XXV. The highway leading from Natural Bridge toward Lynchburg crosses it a short distance east of Natural Bridge, the descent being approximately 250 feet. It will be noted that Cedar Creek flows across this escarpment just south of Natural Bridge.

The preceding three lines of evidence in support of two contrasted Harrisburg surfaces, the one developed by the master stream, the other formed by tributary streams, are supported not only by field studies but equally well by two series of profiles, the one from northeast to southwest, the other northwest to southeast (Fig. 3). The chief peculiarity about the contrasted erosion surfaces of the Natural Bridge area lies in the fact that one of the tributary streams flowed parallel with, but almost opposite to, the direction of the main stream. This is primarily responsible for the escarpment which runs parallel to the drainage lines. It is possible that the limestones underlying the escarpment may be a little more resistant than those farther west near the Plank Road. This factor is of minor significance as compared with the normal slopes of Harrisburg erosion surfaces as they are developed by master streams and their tributaries.

The depth of dissection of the higher basin west of James River in the Natural Bridge region is further testimony in support of the idea of two Harrisburg surfaces (*Plate XXIII*). Within a distance of two miles from its mouth at Gilmore Mills, Cedar Creek has cut into the Harrisburg surface to a depth of at least 300 feet. At Natural Bridge, where Cedar Creek has an elevation of approximately 950 feet, the erosion surface on the surrounding hills is about 1300 feet, giving a relief of 350 feet. Other streams such as Roaring Run and Rocky Run, which empty into the James between Natural Bridge and Buchanan, have impressive gorges in the margin of the upland to the west. These streams have younger valleys and are more deeply intrenched below the upland level than is common or expectable in this region. The writer has been unable to find other examples of such youthful valleys

and such deep dissection in the Appalachian Valley except where piracy has occurred. The explanation for the above is apparently to be found in the capture by these streams of drainage territory which formerly belonged to streams flowing in another direction.

The last line of evidence against a single Harrisburg erosion surface and in favor of two, is found in the lower part of the basin of Cedar Creek. The road leading from Natural Bridge to Gilmore Mills is a favorable route for a consideration of this feature. A short distance south of the Bridge, one descends from the higher Harrisburg basin to the lower basin, about 1050 feet in elevation. One can see from this point the continuation of the lower surface toward the northeast and southwest. It is about 50 feet higher here than along the Harrisburg valley walls of the James. The contrast between the two levels is shown in Plate XXIV. From this point to Gilmore Mills, Cedar Creek is flowing through an area that was eroded down to the Harrisburg surface of the James River, while above this point the stream is flowing through country that was peneplaned at the same time but at an appreciably higher level. Thus Cedar Creek flows across an escarpment at least 250 feet high. This is entirely inconsistent with the theory that Cedar Creek had its present position in the Harrisburg cycle. Except where rocky barriers cross stream courses, there is always a *gradual* upstream rise of Harrisburg surfaces. As indicated elsewhere, the upper Harrisburg surface descends northeastward *across* the present course of Cedar Creek. Cedar Creek flows eastward, almost parallel with the Harrisburg divide between northeast-flowing and southwest-flowing streams, as shown by the profiles (Fig. 3). The present position is apparently different from the one it had in the Harrisburg cycle.

If the above is true, it is obvious that previous theories of origin of Natural Bridge, based upon the early existence of Cedar Creek in its present position, are not tenable. It is barely possible, but wholly unlikely, that Cedar Creek took its present course late in the Harrisburg cycle. If Cedar Creek did not have its present position in the former cycle, it will be necessary to reconstruct an entirely new drainage history for the region as a whole and to develop a different theory of origin for Natural Bridge.

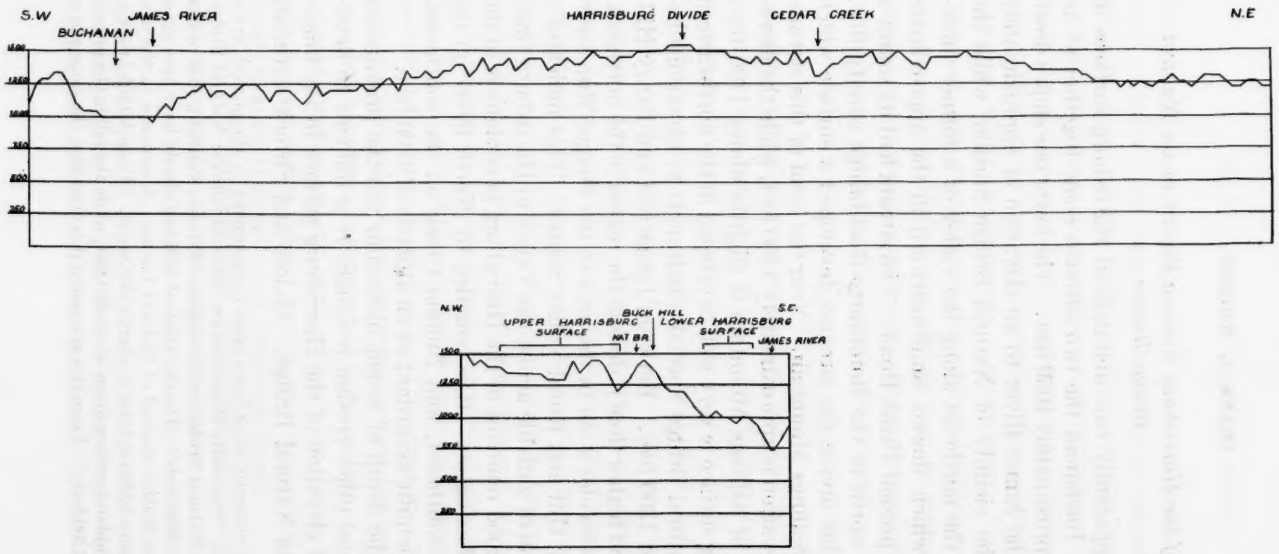

FIG. 3. PROJECTED PROFILES ACROSS THE BASIN OF CEDAR CREEK

Each profile covers a belt of country a mile wide. Note that the Harrisburg surface slopes northeast and southwest from the "Harrisburg divide." The northeast-sloping surface in the longer profile cuts across the course of Cedar Creek, which trends to the southeast. Natural Bridge is not against a steep slope as shown in the short profile. The arrow merely indicates its position with reference to the escarpment.

Summary of the Harrisburg Erosion Record in the Natural Bridge Region

There are apparently two well-defined Harrisburg surfaces in this area. At Buchanan the two surfaces come together at an elevation of approximately 1050 feet. The lower one slopes down the valley of the James River to an elevation of approximately 1000 feet in the vicinity of Natural Bridge Station, while the upper rises to the northeast along the valley of a former subsequent stream which flowed southwestward in the approximate position of the present Plank Road. The stream had its source a short distance north of the Botetourte-Rockbridge county line. Northeast of this divide the streams developed a surface which slopes toward Sallings Mountain. Near the head of this stream, the present elevation is approximately 1400 feet, while the elevation just west of Sallings Mountain is slightly above 1100 feet. The Harrisburg surface is very well developed in the northeastern part of the Natural Bridge Special quadrangle at elevations between 1250 and 1300 feet. Between Longwood and Fancy Hill, it seems to stand higher than it does in the region to the northeast, and also above its elevation in the area of the Poague Run basin between Fancy Hill and Rural Valley School. This indicates a possible position of a divide across the Valley in Harrisburg time. An especially good remnant of the Harrisburg peneplane is in the area south of Lexington. It is bounded by North River on the northeast and southeast, and Buffalo Creek on the southwest. The hilltops are quite accordant at an altitude of 1200 feet.

Because of the depth of recent dissection and the prominence of Buck Hill and other erosion residuals, it is difficult to determine the exact elevation of the Harrisburg surface in the immediate vicinity of Natural Bridge. Malott and Shrock[5] estimate

[5] These authors correctly refer to an error in statement by the present writer (*70*), where he says, "Successive elevations are about as follows: Natural Bridge, 1100 feet; between Natural Bridge and Lexington 1200 feet; Fairfield, 1600 to 1700 feet; Middlebrook, 2000 feet." The elevation of 1100 feet should have been given for Natural Bridge Station instead of Natural Bridge. A sentence in the next paragraph of the same bulletin helps to clarify this point. "From Middlebrook to Balcony Falls the upland surface drops about 900 feet, while the fall in the present drainage is about 1200 feet." From this statement it is clear that the same eleva-

that, "In the interstream spaces (it) has an altitude of about 1400 feet." This is a fair estimate of its height in the area near Highbridge Church, but the writer is of the opinion that it is a little too high for the area immediately surrounding Natural Bridge where the general accordance is more nearly 1300 feet. Within a short distance to the west or southwest it approaches the figure given by Malott and Shrock. At the same time, as already explained, it is impossible to give a general estimate of the present elevation of the Harrisburg surface for the region as a whole because of the rather rapid downstream descent, particularly in the basins of the tributary subsequent streams.

Drainage Changes

Assuming that the restoration of the Harrisburg surfaces as given above is essentially correct, we must still account for the changes in drainage which have taken place since the close of the Harrisburg cycle. It is obvious that with the uplift which brought the Harrisburg to a close, the streams of the region began to intrench themselves. Furthermore, short tributaries entering James River from the west began to gnaw vigorously into the escarpment which separated the upper and lower basins. Two of the most important streams, those which have secured for themselves the largest share of the upland drainage, enter the James at points where the master stream is undercutting the escarpment. The drainage area of Rocky Run formerly discharged toward the southwest along the Plank Road. This territory was captured by a stream working into the escarpment from the east. The same thing has happened in the case of Roaring Run. The tributaries of these streams, which head against the Short Hills and flow eastward across the Valley, flowed formerly toward the southwest along the general direction of the Plank Road.

Another stream heads near Highbridge Church and flows southward, then southeastward into the James. The upper parts of these valleys are broadly open, but downstream they are ex-

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tion is used for Balcony Falls as for Natural Bridge, which is obviously untrue. The estimate was meant for the area of Natural Bridge Station. After more study it is now found to be too high by approximately 100 feet.

tremely youthful and are characterized by rapids and local falls. It seems to be a case of an upland surface that is being rapidly dissected by vigorous pirate streams. As one travels from Buchanan northward along the Plank Road, now the Lee Highway, with map in hand, it is very easy to trace the upstream slope of the Harrisburg surface. Passing across the moderately flat area north of Purgatory Creek, where the word "Plank" in Plank Road is printed on the Natural Bridge Special map, he notices the more dissected terrain bordering Rocky Run, but the striking feature is the fact that the hills preserving the erosion surface rise uniformly northeastward across the valley of Rocky Run and its tributaries as well as across the valleys of the tributaries of Roaring Run. The erosion surface slopes southwestward, while the present streams flow in general southeastward, a fact difficult to explain except on the basis of piracy.

Following the Plank Road across the county line, one is impressed by the open character of the valley near the head of Roaring Run. It appears to have been very little modified since the Harrisburg cycle. The pirate stream has not yet had time to dissect deeply this part of the valley. The stream flowing to the northeast on the opposite side of the divide has a steeper gradient and a notably younger valley. At present this tributary of Cedar Creek is gaining ground on Roaring Run. This is interesting, in view of the fact that Roaring Run has already captured this territory from a southwesterly flowing stream. It appears to be a case of stealing from a pirate.

A significant factor in this diversion of drainage to the southeast is the belt of limestone sinks which occurs along the eastern rim of this escarpment. A part of the run-off is at present being carried through subterranean channels, and it is likely that this was also true in the Harrisburg cycle. At any rate the sinks have certainly played a part in promoting the development of these southeast-flowing pirate streams.

Cedar Creek is the largest of the streams which have been led to take southeasterly courses since Harrisburg time. In view of its connection with Natural Bridge, however, the history of Cedar Creek will be reserved for later consideration.

The Harrisburg erosion surface can be identified in the Lexington-Buchanan area with reasonable certainty. It is as well developed and as well preserved here as in most parts of the Appalachian Valley. Its interpretation, however, rests upon the recognition of different Harrisburg surfaces with their upstream rise, and also upon the recognition of the deep dissection of the higher basin by pirate streams, especially in the vicinity of Natural Bridge and along the escarpment between Natural Bridge Station and Buchanan. In other parts of this region there is nothing peculiar or unusual about the development or preservation of the Harrisburg surface.

Origin of the Natural Bridge

Theories Previously Offered

The theories of origin of the Natural Bridge of Virginia have been so carefully reviewed by Malott and Shrock (*44*) and also by Reeds (*47*) that it would seem unnecessary to go into detail. If the record of Harrisburg erosion has been correctly interpreted in the preceding pages, none of the published theories would be acceptable without serious modification. All of them have been based upon the supposition that Cedar Creek has long flowed in its present position and that its youthful characteristics are due to its rejuvenation through uplift.

The Walcott (*64*) theory is summarized on an earlier page. It is so plausible that its wide acceptance is easily understood.

Malott and Shrock point out an outstanding objection to the Walcott theory. If the Bridge, they say, really represents a remnant of the former floor of Cedar Creek, it should occupy the position of a valley bottom, whereas it is actually against a slope. The surface rises from the level on which the hotel is located southward across the Bridge up to the hills beyond. While it may be argued that later erosion has altered the topography in the vicinity of the Bridge, it is hardly likely that it would have changed the surface so markedly. At the same time, it would not seem necessary that the subterranean channel of Cedar Creek should have been located immediately beneath its abandoned surface course.

All in all, there does not seem to be any serious weakness in Walcott's theory except, as previously stated, Cedar Creek in all probability did not flow in this position. Walcott assumed that, following the uplift at the end of the Harrisburg cycle, a fall formed at the mouth of Cedar Creek at Gilmore Mills. This fall retreated upstream toward the Bridge, when Cedar Creek, at some point above the Bridge, began to sink in its bed and to find a lower outlet at the base of the fall.

In the study of the region, Malott and Shrock find what they regard as wholly adequate support for the Gilmer theory. Their restatement of this very early theory of origin, accompanied by diagrams, is very convincing. They summarize the case in the following words: "The finding of the evidence which conclusively proves that Cedar Creek formerly followed a great meander curve or loop about a spur of nearly horizontally bedded limestone fully substantiates the Gilmer theory of the origin and development of Natural Bridge. It furnishes a perfect clew to the conditions which made subsurface diversion possible. Cedar Creek did find a subterranean passage beneath the ridge (spur), and this passage was developed into a cavern tunnel. The roof-rock, especially at the ends and more particularly at the upper end, weakened and, lacking sufficient support, gradually fell into the deepening tunnel and was dissolved and washed away. A remnant of the roof-rock, however, still remains over this much shortened tunnel and forms the magnificent natural span over the steep-walled, cavern-born canyon. The Walcott theory of the origin of Natural Bridge necessarily becomes untenable, as it has no evidence to support it. The evidence is wholly and conclusively in support of the Gilmer theory. That this evidence had not been discovered long years ago, very probably is due to the facts that the canyon and the bridge are viewed almost wholly from below and that the little visited areas adjacent to the canyon are densely wooded. Moreover, the attractiveness of the theories of origin, and especially the completeness of the Walcott theory, may have discouraged the investigation of the field evidence which has awaited this long while."

The evidence referred to in the above quotation consists

largely in the presence of what the authors call a meander loop which swings around to the north of the Bridge and unites with the valley of Cascades Creek. Distributed along this valley, but particularly at the wall of the canyon, there are boulders of sandstone and quartzite, believed by the authors to have been derived from the Short Hills to the west. In addition, the favorable structure at the Bridge and other possible contributing factors are mentioned.

The meander loop which is postulated by these writers consists of a swing of approximately a mile around the hill on which the hotel is situated. Assuming that the stream once occupied this position, it would hardly be possible to call it a meander in view of its great size as compared with the volume of the stream. This, however, does not argue against the theory. The present writer would raise a question as to the sufficiency of the evidence in support of the northward swinging course around the hill. The part of the supposed course between the point where it leaves the present valley and the old road leading westward from the Lee Highway is characterized by numerous sinks. In fact, this is really a sink hole basin without surface outlet. There is nothing especially significant about either the transverse or longitudinal profile of this depression which would indicate its former occupancy by a stream. An examination of the soil and gravels along the old road resulted in the finding of a few partly rounded sandstone pebbles and small boulders. The soil, however, is definitely residual and the number of gravels which might be interpreted as stream-worn is so small that no special significance can be attached to them. Similar gravels occur in other comparable situations in this locality.

Perhaps the greatest weight is attached by these authors to the discovery of a deposit of gravels and boulders on the rim of the gorge at the very point where Cedar Creek is supposed to have left its present valley for its northward swing around the spur. There are two crucial points in this unique boulder occurrence. The first has to do with the rounding, the other with the source of the material. Malott and Shrock say: "On the rim of the upland just north of the sharp meander turn of the stream in the

gorge occur stream gravels and well rounded cobbles of quartzitic sandstone which have been very probably derived from the Massanutten sandstone in Short Hills Mountain at the headwaters of Cedar Creek. These gravels and cobbles in places are several feet in depth and lie considerably more than 200 feet above the bottom of the gorge of Cedar Creek." There are some fairly well rounded specimens, but many are partly rounded or angular.

As to the source of the boulders in the above locality, Malott and Shrock point to the Short Hills. If this can be demonstrated it is not necessary to even consider the degree of rounding. Several specimens from this deposit by the side of the canyon were submitted to Dr. Charles Butts[6] for examination. He identified the dark red specimens as definitely belonging to the Clinton formation which is exposed in the Short Hills. The Clinton does not occur between the Short Hills and Natural Bridge. The red specimens appear to be, in general, more rounded than the lighter-colored fragments. The latter may have been derived from local sources.

The topographic situation of this boulder and gravel deposit detracts from its trustworthiness as an indicator of an abandoned valley. It would seem possible to account for those boulders with Cedar Creek in its present position about as easily as by having it occupy the route proposed by Malott and Shrock. It is surprising that there are no good boulder deposits along this old "valley" except at the very point where it leaves the present valley. Rounded gravels and boulders of Clinton sandstone are widely distributed in the area surrounding Natural Bridge, and consequently their value in restoring former drainage lines is slight, except where supported by other evidence.

It seems impossible to fit the above theory into the regional history as outlined on earlier pages. If Cedar Creek took its present course as late as the close of the Harrisburg cycle, it would be hard to reconcile this fact with the subterranean cut-off of a meander route as required in the revised Gilmer theory. It seems more likely that the underground channel or outlet was developed by a concentration of sink drainage just west of the Bridge before

[6] Butts, Charles; personal communication.

Cedar Creek was there. In other words, Cedar Creek may never have had a surface course across the Bridge, as postulated by Walcott, or around the Bridge as stated by Malott and Shrock.

Proposed Limestone Sink Piracy Theory.

In attempting to find an adequate basis for an explanation of Natural Bridge and the gorge of Cedar Creek above and below the Bridge, a study has been made of the possible factors which could have been responsible for the piracy of Cedar Creek and its diversion to its present position under Natural Bridge. It seems to the writer that there were present in this locality the very conditions which would make such a change not only possible but relatively easy. In short, the flow of surface drainage through sinks near the eastern margin of the escarpment to a stream gnawing into the upland, would provide favorable conditions for the development of a sink drainage basin on the upper level, with its outlet following a subterranean course to a stream on the lower level.

The steep gradient of this outlet stream would enable it to abstract drainage territory from the northeast-flowing tributaries of ancient Cedar Creek and finally to tap the waters of Cedar Creek itself. On the basis of this theory, the present Cedar Creek never flowed as a surface stream across the east-facing escarpment separating the upper and lower levels. It was led under the escarpment by a pirate stream developed from a large sink basin which had its subterranean outlet to the east.

Features of Underground Drainage Near Natural Bridge. There are several rather interesting features in the subterranean drainage of this locality. In general, it appears that the movement of underground water is chiefly to the east, as would be expected from the eastward-dipping structure above the Bridge and the location of the master stream to the east. In the following paragraphs some of the features of the underground drainage near the Bridge will be described briefly in order to show the possibility of an earlier diversion of Cedar Creek as suggested in the proposed sink piracy hypothesis.

A local feature of special interest is the small temporary stream which heads in springs about a half mile west of the Lee Highway and flows toward the valley of Cascades Creek. In fact, it is shown on the Natural Bridge Special map as flowing into Cascades Creek about two-thirds of a mile north of Natural Bridge, and to the casual observer it appears to be a normal tributary joining its master stream. As a matter of fact it empties into limestone sinks in the gardens of the Natural Bridge of Virginia, Inc. (*Plate XXVI*), and has no surface connection with any stream, although there is a well-marked valley leading from the sinks northeastward to Cascades Creek. The rocks at the sink holes are dipping to the east and it is likely that the underground flow is in this direction, although tests with fluorescein have thus far given no clew to its outlet.

Almost a mile above the Bridge, the visitor finds one of the most interesting local attractions of the Natural Bridge area. In the valley wall of Cedar Creek, about thirty feet above the level of the stream, the limestone rocks have been blasted away to expose a swift, east-flowing, subsurface stream known as Lost River. According to Reeds the rocks at this point dip twenty degrees toward the southeast, and it is likely that the water follows the dip slope until it unites with Cedar Creek a few yards downstream.

Buck Hill is a prominent topographic feature, just northeast of the Bridge, which rises to an elevation of 1450 feet. The map shows a sink on the north side of the hill at a height of more than 1400 feet. On the west side of the hill, there is a sink which leads into a rather large underground cavern. It is said to trend eastward for a distance of several thousand feet, and to be occupied in part by a small stream flowing in the same direction.

About a mile west of Natural Bridge the writer was shown an opening under a limestone ledge at the top of an east-sloping hill. The owner of the farm stated that after heavy rains the water which enters this opening, unless artificially prevented, empties into his well in the floor of the valley to the east.

Numerous sinks occur in the area under consideration. They are found, as previously stated, along the floor of the "abandoned valley" of Cedar Creek as described by Malott and Shrock. They

also appear along the highway leading southwest from the Bridge, and again near Rockypoint and Indianrock. It will be seen that these sinks are in a belt trending northeast and southwest, just west of the escarpment. In the woods southeast of the Bridge, the surface in some places is pitted with them. Isabella's Stairway is particularly noteworthy. This is a sink which opens into an almost vertical shaft. By the use of a few artificial steps, people descend through this "Stairway" and come out at an opening not far above the level of Cedar Creek. The writer noted round river rocks tightly cemented in the ceiling and sides of the lower part of this nearly vertical passage. This feature is almost directly in line with the course of Cedar Creek just below the Bridge and illustrates how the surface drainage may have been carried through a number of different channels which later united in a single stream.

The development of sink drainage near the eastern rim of the escarpment before the piracy of Cedar Creek occurred would be similar to the drainage conditions which now prevail in the region called Little Levels near Hillsboro, as shown on the Marlinton, West Virginia, quadrangle. An area of ten to twelve square miles has no surface drainage except streams which end in sinks. The area is several hundred feet above the level of Greenbrier River which borders it. Short tributaries of this stream are gnawing back into the upland, but as yet they have not gone far. There appears to be no marked concentration of any of the upland drainage which would be necessary for the formation of a natural tunnel. This may be realized, however, when Millstone Creek, which drains a sink basin on the western margin of the Marlinton quadrangle and the eastern margin of the Lobelia quadrangle, finds its outlet in one of the surface streams flowing into the Greenbrier.

The conditions which perhaps most nearly correspond to those which are presumed to have existed in the Natural Bridge region near the close of the Harrisburg cycle are shown in the great sink basin which extends northeastward from the belt of sinks just west of the Bridge. The divide between this large area of interior drainage and the head of Cascades Creek is along the Lee Highway about two miles north of Natural Bridge. Turning

eastward on a county road leading from this highway, one can travel for two miles along the side of a broad lowland which has no surface outlet. It has the appearance of a subsequent stream valley. The water passes out of the basin through various sinks distributed along its floor, and through a large subterranean outlet near the eastern end. After heavy rains, the outlets are not large enough to carry off the water, and a lake forms which sometimes covers acres of ground. Just east of this basin, on a slightly lower level, there is a large spring which flows throughout the year regardless of whether or not water enters the main outlet in the sink valley. Objects dropped into the stream in the sink basin come out in the spring on the other side. A valley or basin of this size is the product of the coalescence of a number of sinks, and it is this process which may have been responsible for the development of the initial drainage west of the Natural Bridge.

Evidence in Support of the Present Theory. The first feature which points toward piracy in the Natural Bridge region is the deep wind gap in Sallings Mountain west of Glasgow. A photo of this gap is shown in Plate XXVII. The altitude of its floor is slightly above 1100 feet, which is the approximate elevation of the Harrisburg surface west of the mountain. Another fact indicating its former occupancy by a stream is the occurrence of rounded boulders and gravels on both sides of the gap. They are much more abundant on the east than on the west. The possibility of their having been deposited on the east side of the gap by North River, is very remote in view of the topographic location of the boulders. Some of the boulders rest on the edges of deeply weathered shale and form a fairly well assorted layer dipping to the east.

The high degree of rounding exhibited by some of these boulders indicates stream wear. Their topographic situation and their rounded character point strongly toward their having been deposited by a stream flowing from west to east across the Valley. A crucial point is the question of their origin. Butts[7] has recently identified the rounded, red specimens as belonging to the Clinton

[7] Butts, Charles; personal communication.

formation whose nearest exposure is in the Short Hills. This formation does not occur in the Blue Ridge to the east, and hence the boulders must have been deposited by a stream which drained the Ridges to the west. North River, Buffalo Creek, and Cedar Creek are the only streams which could have occupied this position. There is no field evidence to indicate any post-Harrisburg changes in the courses of Buffalo Creek and North River. On the other hand, the evidence points strongly to Cedar Creek as the stream which formerly occupied the wind gap in Sallings Mountain.

A second line of evidence in favor of the piracy of Cedar Creek is its peculiar course. After leaving Short Hills, it swings southward along the Plank Road, then turns east across the Valley. That it should first turn southward rather than eastward is not expectable, but in itself is not especially significant. Of much greater importance is the low col near the head of Poague Run just opposite the point where Cedar Creek leaves the mountain. From this col, one can look down the valley of Poague Run across several local divides to the wind gap in Sallings Mountain. This alignment of features is distinctly suggestive of a former stream valley, although positive evidence is largely lacking due to the relatively rapid erosion of limestone.

The youthful characteristics of the present valley of Cedar Creek in the vicinity of Natural Bridge are difficult to overemphasize. The transverse profile is v-shaped and the walls are actually precipitous. The ungraded character of tributary valleys, and Lace Falls, Plate XXII, are other indications of youth. These facts point to the recent shifting of Cedar Creek to its present position, or to a great increase in its volume, or both.

A somewhat careful search for stream gravels was made between the Sallings Mountain wind gap and the Short Hills. They were found on the shallow col on the first low ridge northwest of Sallings Mountain. Samples were taken which comprised well-rounded, red sandstone boulders and also light-colored specimens. The red material is more significant than the light because it indicates more definitely the Clinton formation which appears only in the mountains to the west.

Another occurrence of boulders was found on the side of a hill on the road leading from the Lee Highway, two miles southwest of Fancy Hill, to Longwood. The boulders in this locality are numerous and apparently comprise the same types of materials as those found in the wind gap of Sallings Mountain. Light quartzites seem to predominate, but red specimens, well-rounded, also occur.

On the low divide between the head of Poague Run and Broad Creek, there are abundant sandstone fragments, some partly rounded. They are decidedly less well-rounded than those observed in the wind gap in Sallings Mountain, but they are apparently the same material.

Samples of stream gravels and boulders, including fragments of the Clinton formation, were collected from the present stream bed of Cedar Creek along the Plank Road, and at points downstream as far as Natural Bridge.

The writer has found sandstone and quartzite gravels showing more or less rounding in several other situations in this region. Scattered boulders were found in the valley of a tributary of Poague Run about a half mile southwest of the larger occurrence on the road to Longwood, as previously described. They are abundant in the later terrace deposits of the James River between Natural Bridge Station and Glasgow as well as along the valley of North River near the base of the Blue Ridge. No material comparable to the reddish-colored sandstone was found in a search of a large deposit of boulders in the bed of a stream flowing from the Blue Ridge into North River. Some Clinton gravels were found on the hills near the southern end of the large sink basin northeast of Natural Bridge. Material exhibiting variable degrees of rounding occurs in quantity near the rim of the gorge of Cedar Creek a short distance above Natural Bridge, as described by Malott and Shrock. The boulders are not as well-rounded as those in the wind gap in Sallings Mountain but they have doubtless suffered stream wear. Part of the material in this deposit can be accounted for locally but there are some specimens of red sandstone from the Short Hills. Similar materials occur on the low divide northeast of Highbridge Church.

Assuming that the red material in these various gravel deposits has been derived from the Short Hills to the west, it is still not clear how we shall account for some of the above occurrences. The testimony of the boulders and gravels is not regarded by the writer as particularly helpful in tracing the exact positions of former streams, except, as in the case of Sallings Mountain, where the position of the stream is indicated by the wind gap. The gravels here definitely show that the source of the stream was in the Ridges to the west. The wind gap was clearly formed by a stream which occupied it until the close of the Harrisburg cycle. The most probable course of the stream which flowed across Sallings Mountain is outlined by several of the gravel occurrences referred to above and by the col at the head of Poague Run. The exact position, however, is unknown, and it may not have been related to any of the gravel occurrences previously described. In view of the fact that a former stream course is fairly well indicated by a wind gap, a col, rounded gravels, and the further fact that the present Cedar Creek has characteristics which clearly indicate that its present position has been acquired since the close of Harrisburg time, it would seem logical to conclude that the stream which cut the wind gap in Sallings Mountain was the ancestral Cedar Creek, which was later diverted to its present position. In fact, there is practically no alternative because no other stream has a position which could so easily have been taken as a result of diversion from a course across Sallings Mountain.

The Cause of the Piracy. Postulating the above changes in the history of Cedar Creek, we must next seek an adequate cause. Perhaps the enlargement of a sink drainage basin, and the coalescence of smaller sinks into larger ones, in the area between Red Mills and Natural Bridge first provided a subterranean outlet for the surface discharge which joined a small stream at the eastern base of the escarpment. Through piracy, the drainage area west of Red Mills was diverted to this subterranean stream. Eventually the upper waters of Cedar Creek were captured near the base of Short Hills.

The writer would not attempt to trace step by step the series

of subterranean and surface stream piracies which resulted in the development of the present Cedar Creek. Cols, and low divides between the heads of subsequent streams, are so common in limestone regions that they have little significance in tracing drainage changes. It is quite probable that a tributary of the ancestral Cedar Creek rose near Highbridge Church and flowed northeastward by Red Mills. There is an extremely low divide between the tributary which enters Cedar Creek from the north, at Red Mills, and Poague Run. There is also a possibility of a former stream along the strike valley east of Natural Bridge and Buck Hill. In fact, there are many possibilities in the evolution of the present Cedar Creek system, and it would be extremely difficult to demonstrate the correctness of any detailed restoration. Cedar Creek and its upper tributaries have dissected the region in the present cycle to such a depth that the evidence of former stream courses has been destroyed.

The theory as outlined above seems to explain the features of the Natural Bridge locality and also fits into the regional history. Natural Bridge is accounted for in much the same way as explained by Gilmer and Walcott, as a remnant of the roof of an underground tunnel. Lace Falls represents an ungraded portion of a young valley. The gorge is the unroofed portion of a former tunnel which has been modified by weathering and erosion. The tunnel on this theory originally extended as far east as the margin of the escarpment. Cascades Creek (*Plate XXVIII*) at present discharges into Cedar Creek just below the Bridge, but in Harrisburg time it might have flowed northeastward along the well-marked subsequent valley which extends to the eastern margin of the Natural Bridge Special map. The little valley southwest of the Bridge along the Lee Highway might have been occupied by a tributary of Cascades Creek which crossed the present gorge just below Natural Bridge. In view of the fact that the tunnel of Cedar Creek extended as far east as the edge of the escarpment, Cascades Creek could not have entered Cedar Creek on the surface before the collapse of the tunnel roof at the present junction. It may have emptied, for a time, into a sink, such as the vertical

sink described as Isabella's Stairway, and joined Cedar Creek underground. This possibility is indicated by the fact that the little garden stream, shown on the map as a surface tributary of Cascades Creek, actually plunges underground through a sink.

Within a mile of Gilmore Mills, Cedar Creek makes a pronounced eastward bend that has the appearance of an entrenched meander. The writer studied this feature as well as the somewhat less distinctive bend downstream. It should be remembered that these bends are on the Harrisburg surface of James River, and their only unusual characteristic is their great width. If a short stream flowed in this position during the earlier cycle, it is quite conceivable that it was winding leisurely in its course. Such a small stream would certainly have a very narrow meander belt. If these are true intrenched meanders it would appear that their great depth is due to the fact that there has been an enormous increase in volume. It is a well-known fact, however, that lateral cutting may greatly exceed downcutting in a rejuvenated meandering stream. If the stream had moderate meanders in the Harrisburg cycle, the increased volume following the piracy of Cedar Creek would serve to widen these meanders or bends.

The sink piracy theory for the origin of Natural Bridge is presented as a tentative explanation. If the regional history has been correctly interpreted, none of the theories of origin previously published would be acceptable without serious amendment. That being the case, the most plausible theory that the writer has considered involves the diversion of Cedar Creek from an ancestral course across Sallings Mountain to its present position under Natural Bridge. This may have been accomplished by the headward growth of a stream gnawing back into the escarpment, combined with the effects of sink hole drainage.

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PLATE I

SURFACE OF ALLEGHENY MOUNTAIN, SHOWING MODERATE DISSECTION OF THE SCHOOLEY PENEPLANE

Near "Top of Allegheny." (Bull. 11, Virginia Geological Survey)

PLATE II

MOLE HILL, A CONICAL MONADNOCK ON THE HARRISBURG PENEPLANE NEAR HARRISONBURG, VIRGINIA

(Bull. 11, Virginia Geological Survey)

PLATE III

WOODED HARRISBURG SURFACE ON THE EAST SIDE OF THE VALLEY OF SOUTH BRANCH OF POTOMAC RIVER, BETWEEN PETERSBURG AND MOOREFIELD, W. VA.

With Plate IV, a panorama

PLATE IV

WOODED HARRISBURG SURFACE ON THE WEST SIDE OF THE VALLEY OF SOUTH BRANCH OF POTOMAC RIVER, BETWEEN PETERSBURG AND MOOREFIELD, W. VA.

Note its slope from the mountain base toward the stream

PLATE V

HARRISBURG PENEPLANE IN THE LUNICE CREEK LOWLAND. LOOKING NORTH FROM HIGHWAY, ONE MILE NORTH OF PETERSBURG, WEST VIRGINIA

PLATE VI

HARRISBURG PENEPLANE, WITH THE BLUE RIDGE IN THE BACKGROUND. LOOKING SOUTHEAST FROM WINCHESTER, VIRGINIA

(Photo by Dr. Charles Butts)

PLATE VII

HARRISBURG SURFACE OF BROWNTOWN COVE IN THE MIDDLE GROUND, WITH THE BLUE RIDGE IN THE BACKGROUND. SOUTH OF FRONT ROYAL, VA.

PLATE VIII

HARRISBURG PENEPLANE WEST OF EDINBURG, VIRGINIA

Great North Mountain (Schooley) forms the skyline. (Photo by Dr. Charles Butts.)

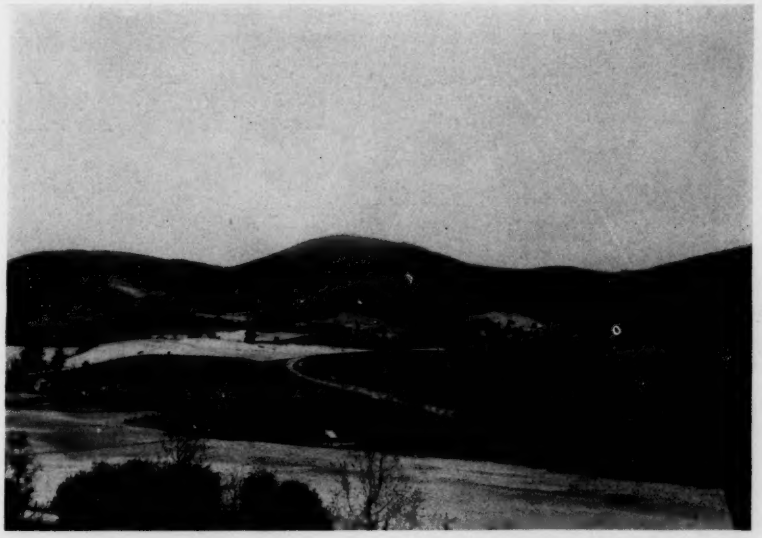


PLATE IX

TERRACE ONE MILE WEST OF MILLBORO SPRINGS, VIRGINIA
(Bull. 11, Virginia Geological Survey)

PLATE X

HARRISBURG LEVEL ON SHALE, FIVE MILES EAST OF STEPHENS CITY, VIRGINIA

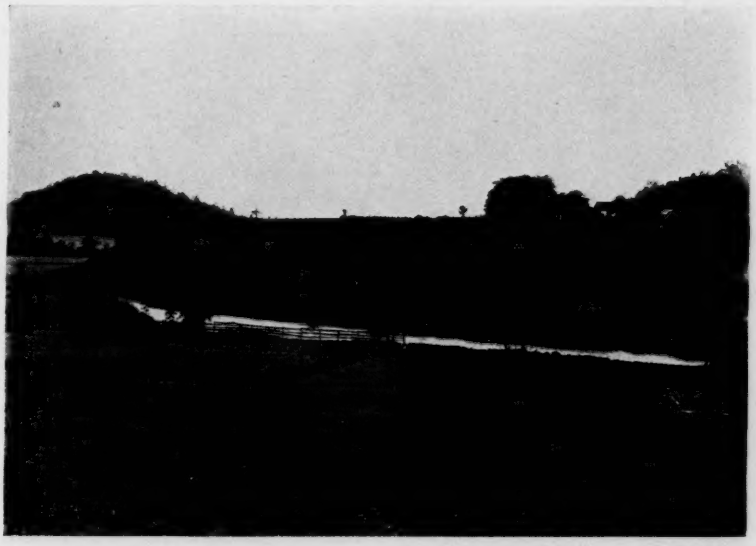


PLATE XI

Shale Level West of Highway from Point Five Miles North of Riverton, Virginia

PLATE XII

Limestone Level East of Highway from Point Five Miles North of Riverton, Virginia. Blue Ridge in the Background

PLATE XIII

HARRISBURG SURFACE ON SHALE AT HILLSDALE, RONCEVERTE, WEST VIRGINIA-VIRGINIA, QUADRANGLE

PLATE XIV

HARRISBURG (?) SURFACE ON LIMESTONE, WEST OF HILLSDALE, RONCEVERTE, WEST VIRGINIA-VIRGINIA, QUADRANGLE

PLATE XV

GREENLAND GAP FROM THE WEST, GREENLAND GAP QUADRANGLE, WEST VIRGINIA

PLATE XVI

IRON GATE, A WATER GAP IN THE NORTHEASTWARD PLUNGING ANTICLINE OF RICH PATCH MOUNTAIN AT CLIFTON FORGE, VIRGINIA

(Bull. 11, Virginia Geological Survey)

PLATE XVII

ANTICLINE OF MARLIN MOUNTAIN-SEWELL MOUNTAIN EXPOSED IN THE GORGE OF KNAPP CREEK, SIX MILES EAST OF MARLINTON, WEST VIRGINIA

PLATE XVIII

HARRISBURG SURFACE OF NEW RIVER DISSECTED BY SOUTH FORK OF ROANOKE RIVER, TWO MILES WEST OF COPPER HILL, VIRGINIA. (CHRISTIANSBURG QUADRANGLE)

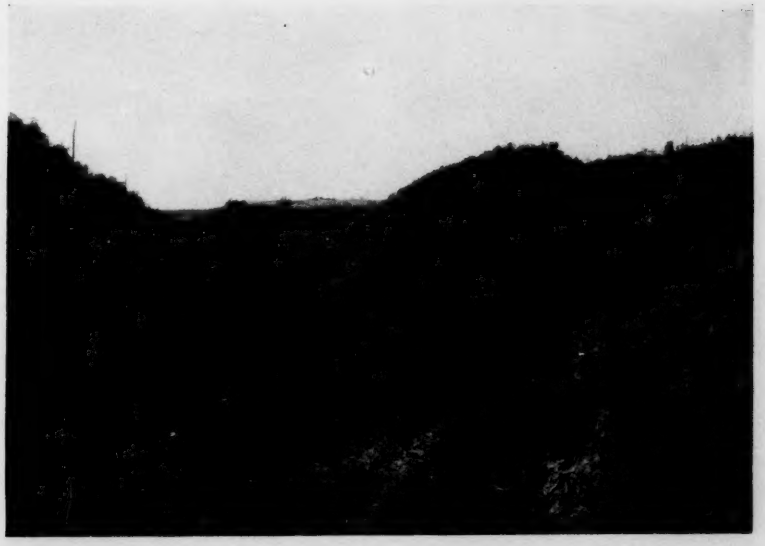


PLATE XIX

HARRISBURG SURFACE OF NEW RIVER DISSECTED BY SOUTH FORK OF ROANOKE RIVER EAST OF HUFFVILLE, VIRGINIA. (CHRISTIANSBURG QUADRANGLE)

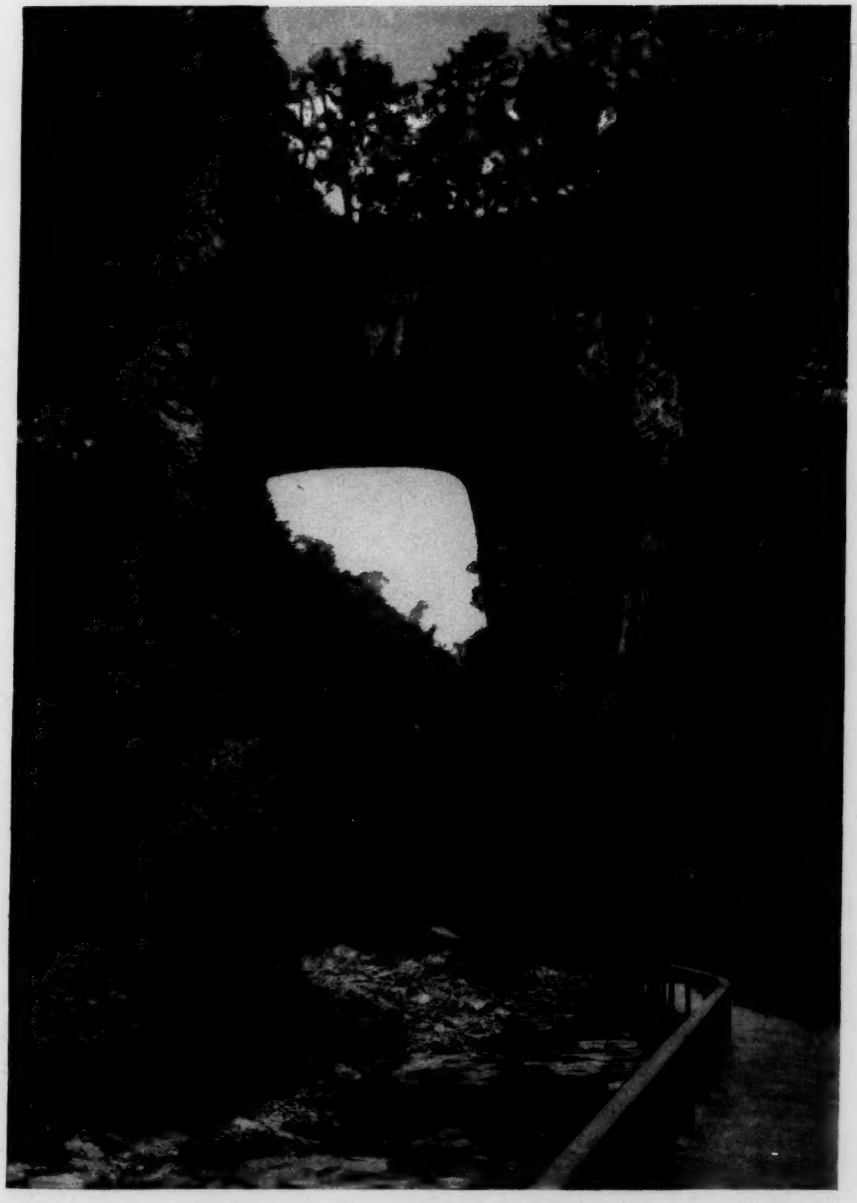
PLATE XX

HARRISBURG SURFACE OF NEW RIVER SLIGHTLY DISSECTED BY TRIBUTARIES OF NEW RIVER WEST OF HUFFVILLE, VIRGINIA. (CHRISTIANSBURG QUADRANGLE)

PLATE XXI

THE NATURAL BRIDGE OF VIRGINIA

(Courtesy Natural Bridge of Virginia, Inc.)



THE NATURAL BRIDGE OF VIRGINIA

PLATE XXII

LACE FALLS ON CEDAR CREEK, NATURAL BRIDGE, VIRGINIA
(From Reeds, "The Natural Bridge of Virginia and its Environs")

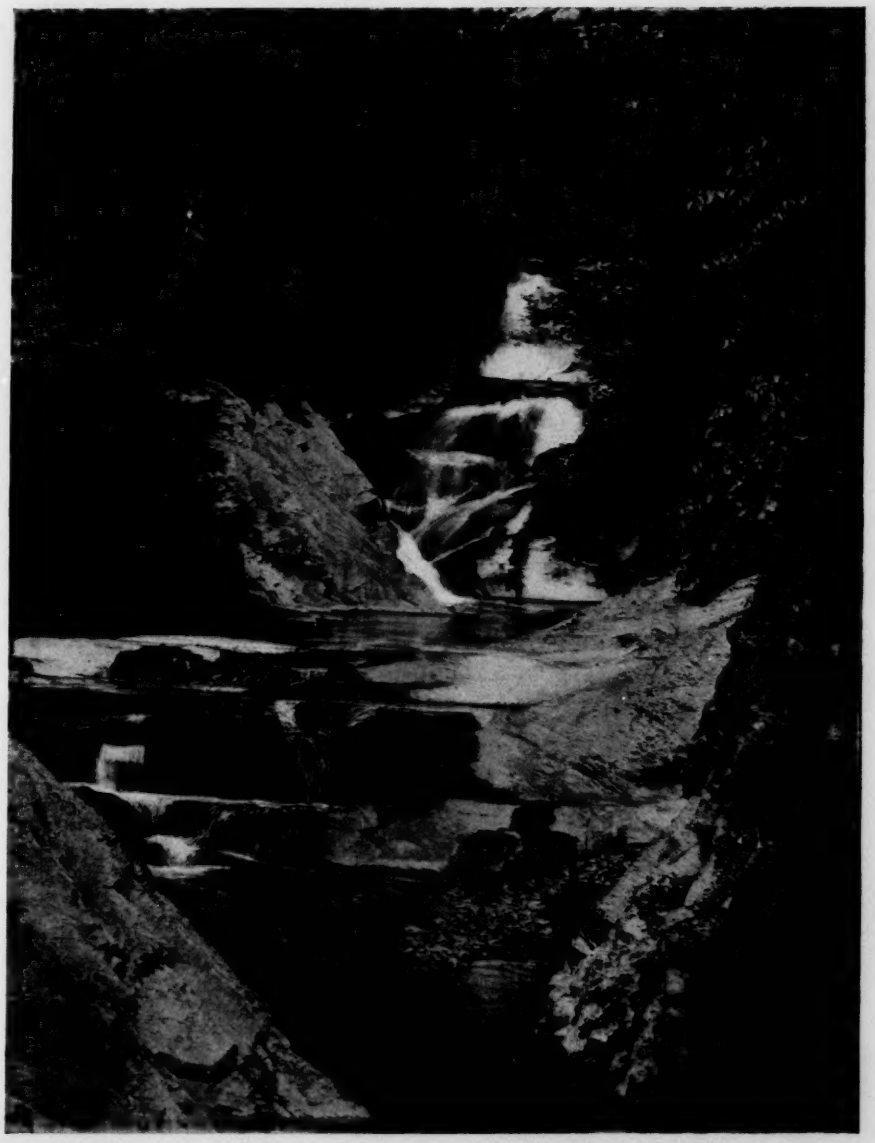


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PLATE XXIII

A Topographic Map of Natural Bridge and Vicinity
(From Reeds, "The Natural Bridge of Virginia and its Environs")

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THE NEWER APPALACHIANS OF THE SOUTH

PLATE XXIV

Escarpment Between Upper and Lower Harrisburg Surfaces One Mile East of Natural Bridge, Virginia. James River Level in Left Middle Ground, Higher Level on Right

PLATE XXV

Lower Slope of Escarpment Separating Harrisburg Surface of James River on Right from Higher Harrisburg Surface to the Left of Photo

PLATE XXVI

SINK BASIN IN THE GARDENS OF THE NATURAL BRIDGE OF VIRGINIA, INC.
(From Reeds, "The Natural Bridge of Virginia and its Environs")

PLATE XXVII

WIND GAP IN SALLINGS MOUNTAIN, FIVE MILES EAST OF NATURAL BRIDGE. THE BLUE RIDGE APPEARS IN THE DISTANCE
(Bull. 11, Virginia Geological Survey)

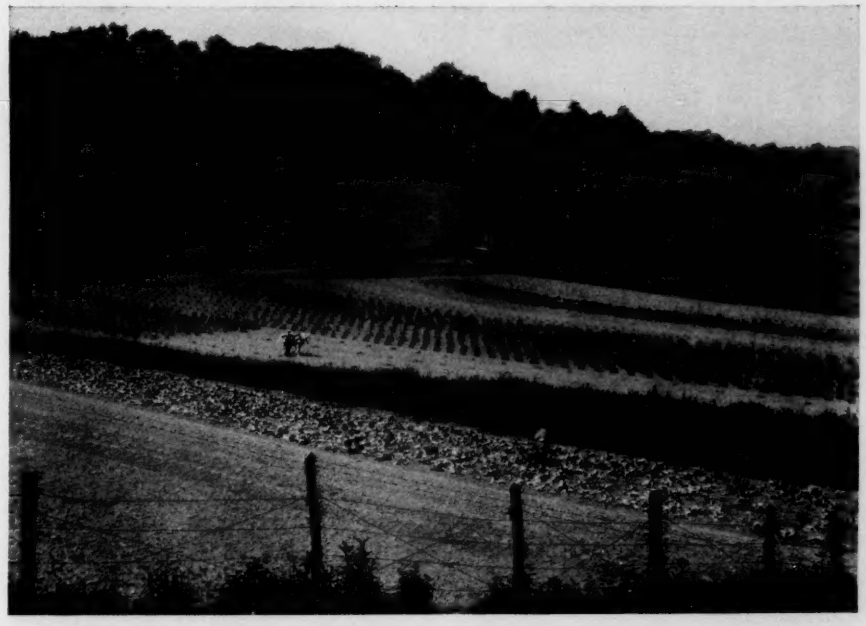
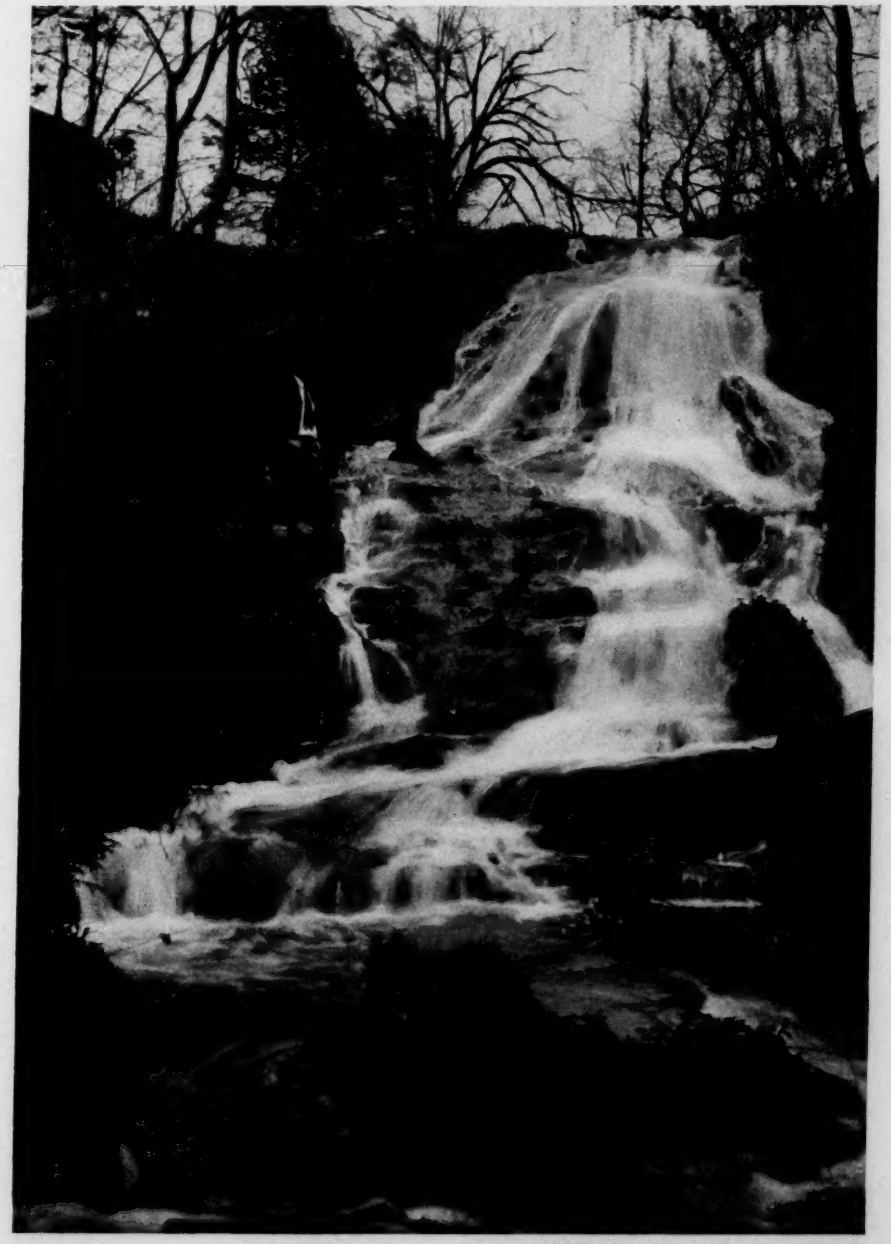


PLATE XXVIII

CASCADES CREEK NEAR ITS JUNCTION WITH CEDAR CREEK
(From Reeds, "The Natural Bridge of Virginia and its Environs")



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